NASA Technical Memorandum 110198

Alternate Assembly Sequence Databook for the Tier 2 Bus-1 Option of the International Space Station

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(NASA-TM-110198) ALTERNATE ASSEMBLY SEQUENCE DATABOOK FOR THE TIER 2 BUS-1 OPTION OF THE INTERNATIONAL SPACE STATION (NASA. Langley Research Center) 416 p

N96-12346

Unclas

G3/18 0071553

August 1995

National Aeronautics and
Space Administration
Langley Research Center
Hampton, Virginia 23681-0001

Table of Contents

1. Introduction

The purpose of this databook is to document the analysis performed to determine characteristics of a proposed alternate Space Station assembly sequence. The proposed assembly sequence (referred to as Tier 2) assumes that Russian participation has been eliminated and that the functions that were once supplied by the Russians (propulsion, resupply, initial attitude control, communications, etc.) are now supplied by the United States. The proposed assembly sequence utilizes the Lockheed Bus-1 to replace much of the missing Russian functionality. The information presented in this databook characterizes on a stage by stage basis the impacts of utilizing the Bus-1 on configuration mass properties, functionality, resource balances, operations, logistics, attitude control, microgravity environment and propellant usage. It should be noted that at the time of this writing, the characteristics mentioned are not yet fully defined for each stage of the baseline International Space Station program; therefore some characteristics will be based on or compared to a TBD/estimated baseline value.

The Tier 2 assembly sequence was defined by the JSC International Space Station program office as a first iteration with the understanding that subsequent iterations would probably be required to address some of the issues that this analysis would identify. The databook includes identification of Tier 2 assembly sequence issues along with suggestions for resolving the issues. Changes to the proposed Tier 2 sequence were minimized during this first analysis cycle.

Several significant issues were identified during this analysis cycle. Many of the earlier assembly flights had less than 90 days of orbital lifetime at the designated assembly rendezvous altitude. There is a shortfall in assembly and maintenance EVA available. The mass properties of the stages during the first half of the assembly sequence lead to large flight attitude angles and poor microgravity environments and will require the development of new CMG momentum managers. There is not enough reboost propellant manifested assuming a $+2\sigma$ atmosphere. There are significant delays in reaching program milestones. Many of these issues can be resolved but at the cost of possible baseline modifications and revisions in the proposed Tier 2 assembly sequence.

2. Groundrules and Assumptions

Assembly Sequence Groundrules and Assumptions

One of the most significant groundrules established for the Tier 2 sequence is assembly at an orbital inclination of 51.6°. This requirement was established so that the Russians could re-enter the program if they chose to do so at some later time. Assembly altitude is restricted to an altitude that will provide a minimum of 90 days lifetime to 150 n.mi. A maximum of 6 Shuttle flights per year for assembly was groundruled to reduce the Shuttle flight rate while allowing the possibility of inserting an additional yearly Shuttle flight to supply EVA and fuel logistics. A FEL date of February 1998 was chosen so that the first node delivery would not be accelerated (assuming a Shuttle flight every other month) and to account for some delay due to Russian non-participation. All flights were manifested with margins, reserves and overhead similar to baseline flights. Although a goal was not to significantly deviate from the baseline assembly sequence, the proposed Tier 2 sequence changes the order of many flights and rearranges some of the cargo elements.

Systems Functionality and Operations Groundrules and Assumptions

Assembly of the Tier 2 Space Station Configuration will require an extensive amount ,of Extra-Vehicular Activity (EVA). In order to perform an assessment of what EVA resources were necessary to complete the assembly, the following assumptions were made:

- The SSRMS checkout will occur on the flight that it is delivered to orbit, ensuring its availability for use on the following flight.
- All EVAs will be performed from the Shuttle during assembly phase.
- There are 2 EVAs available per flight (baseline). Additional EVAs will be available by manifesting extra gases in Shuttle bay.

The EVA groundrules that were used as a baseline for this study are:

- EVA maintenance tasks will not be addressed during this version of the study.
- No EVA will be scheduled during Utilization Flights.

Flight Characteristics Groundrules and Assumptions

Electronic I-DEAS models of the baseline 9/28 assembly sequence were obtained from JSC and modified to match the Tier 2 sequence. These models were used to derive mass and aerodynamic properties for the flight characteristics analysis. The mass of each stage model is typically within a few percent of the actual manifested on-orbit total. Projected areas are derived for each stage by performing ray tracing. A drag coefficient of 2.3 was assumed for all drag calculations.

Several atmosphere models were used to assess the flight characteristics. CMG and RCS attitude control simulations were performed using a peak solar cycle worst case atmosphere (flux=230, Ap =140). Microgravity analysis assumed a $+2\sigma$ atmosphere with a two year shift in the solar cycle to provide a more probable density profile that would accompany a schedule slip. Steady-State envelopes for one, two and four μg were plotted along with corresponding US Lab rack values. The reboost analysis used the same atmosphere as the

microgravity analysis as well as two other atmospheres. See Appendix A for atmosphere tables.

Attitude control analyses without an attached Shuttle were performed on all stages. Attitude control analyses were also performed on Stages 5 and beyond with a Shuttle docked to the station (the Shuttle maintains control of the combined stack till Stage 5). CMG control of the station is performed with the Bus CMGs until the activation of the Z1 truss at which time the station CMGs (4*4745 N-m-s) are utilized. A range of CMG control laws/momentum managers were utilized depending on stage properties.

An optimizer was utilized to calculate reboost efficiency as a function of engine gimbal angle, flight attitude, thruster geometry and configuration mass properties. All stated efficiencies assume a reboost engine gimbal angle of less than ±10 degrees and a flight attitude within ±15 degrees of LVLH. A modified Freedom CDR RCS control algorithm was used for simulating station maneuvers with the Bus.

Logistics Analysis Groundrules and Assumptions:

The US will provide propellant resupply for the ISSA using the Bus-1 and will provide ECLSS for the ISSA using an as yet undetermined delivery mechanism aboard the Shuttle. Using the neutral atmosphere definition as defined in Section 3.2.6.12 of SSP 41163. The altitude strategy is defined as follows:

- For the Assembly Phase: the minimum operational altitude for the on-orbit space station shall be the altitude that provides 90 days of orbital decay to 278 (150 n.mi.).
- Post Assembly Phase: the minimum operational altitude for the on-orbit space station shall be the altitude that provides 180 days of orbital decay to 278 Km (150 n.mi.) and satisfies the quasi-steady microgravity requirements.
- For the Assembly Phase and the Post Assembly Phase: the on-orbit Space Station shall have sufficient skip cycle reserve propellant for reboost to an altitude that results in at least 360 days orbital decay to 278 Km (150 n.mi.) under nominal operations.

3. Systems and Logistics Impacts

3.1 Revised ISSA System Capabilities

3.1.1 Command and Data Handling

Baseline Capability - Russian Services

The baseline Command and Data Handling system is a "hierarchical architecture consisting of data processing components connected using MIL-STD-1553B data buses". The main computational device is the Enhanced Space Station Multiplexer/Demultiplexer (EESMDM), and the main input/ouput device is the Space Station Multiplexer/Demultiplexer (SSMDM). The crew interface to the Command and Data Handling system and payloads is through the Portable Computer System (PCS), which is based on commercially available hardware and software. Three computers are located in the Russian Segment (RS) elements. These computers provide command and data handling of the RS GN&C equipment and other system equipment. Those computers directly supporting the RS GN&C equipment are eventually connected to the U.S. GN&C MDMs that are responsible for controlling the rate gyros, CMGs, and the GPS equipment.

TIER 2 Capabilities

The Tier 2 Configuration makes no significant changes to the baseline C&DH system architecture. The Bus-1 replaces the early computing capability that was provided by the Russian FGB and Service Module elements. By definition, the three Russian Segment (RS) Central Computers in the baseline configuration will no longer be available. All initial computing capability, including the necessary GN&C support functions, will be provided by the Bus-1. As in the baseline, the station C&DH system will ultimately assume control of the station systems and payload operations.

3.1.2 Communications and Tracking

Baseline Capability - Russian Services

Prior to Houston control of the station via the U.S. Lab & TDRSS, all communications with the station involved some aspect of Russian involvement. The initial stages of the build-up involve four different scenarios of communicating with the station:

1. Telemetry and commands via MCC-Moscow (initially Houston directs Moscow by voice, late Moscow routes Houston commands)
2. FGB telemetry downlinked to Houston via NASA modified comm sites
3. FGB command and telemetry at Houston via Russian-provided communications in U.S.
4. NASA onboard crew member control (following Flight 2A)

Houston control of the station occurs following Flight 4A, although the ability to communicate with the station to/from Moscow remains via the Service Module.

TIER 2 Capabilities

All telemetry and commands prior to the activation of the TDRSS antenna and control equipment will be routed through the Bus-1.

3.1.3 Environmental Control and Life Support

Baseline Capability - Russian Services

The baseline ISSA ECLSS functionality consists of Russian- and U.S.-provided services. The phases of ECLSS functions can be described in terms of: 1) the period prior to U.S. Lab activation (i.e., Flights 1A - 6A); 2) the time period between U.S. Lab activation and initial U.S. HAB activation (i.e., Flight 7A-17A); and, 3) the time period following U.S. Hab activation (i.e., Assembly Complete).

Prior to U.S. Lab activation, the Russian Service Module provides the primary ECLSS functionality to all elements. Those functions provide life support for a crew of three and consist of:

- air storage
- oxygen generation
- potable water processing
- temperature and humidity control/filtration
- contamination removal filtration
- trace contaminant removal
- urine/fecal collecuon
- fire detection/suppression
- pressure/temperature sensing
- gas monitoring - CO_2, O_2, H_2O
- CO_2 removal

During the second phase, the Russian elements continue to provide Urine Collection/Processing and Fecal Collection in the Service Module. Following activation of the U.S. Hab, the Russian elements provide ECLSS redundancy.

TIER 2 Capabilities

Utilitization of the Lockheed Bus-1 prior to activation of the Lab results in a complete loss of the ability to support crew on the station at an early stage. In the Tier 2 scenario, this is no longer feasible and therefore the loss of these functions will not impact the revised sequence, except for the fact that there will be no station-based crew to assist with assembly and maintenance EVAs. Entry of Node 1 will occur when the orbiter is docked and providing ventilation and atmosphere control. High Pressure gases (O2 and N2) must be manifested early in the sequence to provide for gas leakage in the Node 1 and Lab.

During the second phase, the U.S. Lab will provide the U.S. elements with Atmosphere Control and Supply, Atmosphere Revitalization, Fire Detection and Suppression, Temperature and Humidity Control, and partial Water Recovery and Management (no potable water processing and monitoring). Waste Management functions will be provided by the Shuttle during the assembly missions.

Levels of redundancy must be investigated to ensure that a fail-safe/operational system is in place without the Russian hardware.

3.1.4 Electrical Power

Baseline Capability - Russian Services

Prior to delivery and activation of the P6 segment on Flight 8, the Russian FGB element provides 119 - 126 Vdc to the United States On-Orbit Segment (USOS) for Node 1, PMA, and Z1 equipment heaters. The current plan is for the Russian segment to provide 1.2 kW of power during the early build-up (Flights 1 - 8).

TIER 2 Capabilities

The Lockheed Bus-1 will provide the 1.2 kW prior to activation of the P6 power segment on Flight 4. In order to meet this power requirement, Stages 2 and 3 will fly in solar inertial flight modes. The Bus-1 produces power at 28 Vdc, requiring a converter on the Bus-1 extender truss to convert to the 119 - 126 Vdc used on the station.

3.1.5 Extravehicular Vehicular Activity/Robotics

There are no changes from the U.S. baseline capabilities, except that all of the EVAs that were planned to be performed with a station-based crew in the baseline program are now Shuttle-based, and they occur during the assembly flight.

3.1.6 Guidance, Navigation, and Control

Baseline Capability - Russian Services

The Russian Segment capabilities consist of the following:

- Determining state vector and attitude (redundant w/ U.S.)
- Generating pointing and support data (redundant w/ U.S.)
- Maintaining attitude non-propulsively (redundant w/ U.S.)
- Executing translation maneuvers
- Controlling attitude propulsively
- Providing desaturation torque

The equipment providing these capabilities that will no longer be present is:

- FGB:
    - X-axis accelerometers
    - Two-axis infrared horizon sensors (2)
    - Single axis rate gyros (3)
    - KURS rendezvous radar
    - Flight computer (internally triple redundant)
- Service Module
    - Star trackers (2 narrow, 1 wide FOV)
    - Sun sensors (4)
    - Horizon sensors (3)
    - Magnetometers
    - Rate gyros -- (1) 3-axis high and (1) 3-axis moderate accuracy
    - GLONASS navigation sensors
    - Flight computers supplied by ESA (3)
- Science Power Platform - 1
    - Gyrodynes - (qty 6)

Cross-strapping between the U.S. and Russian computers passes information on position, velocity, attitude, and attitude rate. Commands for momentum change, pulse patterns, and thruster firing confirmation are also transferred between the U.S. Lab and the Russian Service Module.

TIER 2 Capabilities

All Russian capabilities will be replaced by the Bus-1 during the early assembly stages of the station. See Section 3.3 for a description of the Bus-1 capabilities.

3.1.7 Propulsion

Baseline Capability - Russian Services

The baseline propulsion capability is provided solely by Russian elements. all of which have been flight proven during numerous Russian space activities. The elements consist of the:

- FGB universal block with ~5700 kg of propellant storage capacity
- Service module with ~900 kg of propellant storage capacity
- Progress M with ~1800 kg of propellant storage capacity

The vehicles will be used in a phased approach that is competed with the delivery of a Progress M . The FGB will initially provide attitude control and delta velocity capability until the Service module is attached. Following delivery of the Service module, the FGB will provide propellant storage/transfer only. The Service module will provide attitude control and delta velocity capability until a Progress M is attached, which will ultimately be the vehicle that provides the primary capability for attitude control and delta velocity. When propellant in the Progress M vehicle is depleted, a new Progress M will be launched and the depleted vehicle will be de-orbited.

TIER 2 Capabilities

The propulsive capability of the Tiers 2 configuration is provided solely by the Bus-1 vehicle. The first element launched consists of a Bus-1 vehicle and a space truss that functions as: 1) a spacer between the module cluster and the Bus-1; and, 2) a location for the solar cells that generate power for the Bus-1 and the early stages of the Space Station. During the early stages of the assembly sequence, this Bus-1 will be located aft of Node 1 (the primary location) and will provide all attitude control and delta velocity capability. Stage 10 delivers a second Bus-1 which is located on the zenith face of the P6 Power Module. This second Bus-1 provides a redundant proplusive capability.

The Bus-1's will be replaced as required to ensure a sufficient level of propellant is stored on-orbit.

3.1.8 Thermal Control

There are no changes from the baseline capabilities.

3.2 Logistics Impacts

The Environmental Control and Life Support System (ELCSS) for the ISSA is highly dependent upon the Russians to provide gases to maintain the crew in a safe and habitable environment. These gases will be supplied using the Progress resupply vehicle using a number of high pressure storage tanks. Water will be resupplied by reclaiming potable water from crew waste water. The U.S. side of the ISSA, at Assembly Complete, will include sufficient equipment to provide the six major ECLSS functions required to sustain a six person crew. These functions are : 1) Temperature and Humidity Control, 2) Atmosphere Control and Supply, 3) Atmosphere Revitalization , 4) Fire Detection and Supression, 5) Water Recovery and Management, and 6) Waste Management.

If the Russians decide not to support the ISSA program, the existing equipment included in the U.S. ECLSS would remain the same, but would require that additional gases be provided to the pressurized Station elements. These gases would most likely be delivered using modified Gas Conditioning Assembly (GCA) tanks mounted to an Extended Duration Orbiter (EDO) type pallet.

A summary of the gas supply required before Tier 2 Assembly Complete can be achieved is given in table 3.2-1. The total gas resupply mass to orbit by the end of Assembly Complete is required to be 13,990 lbs.

Table 3.2-1 Gas Supply Analysis at Assembly Complete

Functions	Items	High Pressure Gas	
		Quantity	Mass (lbs)
90-Day Resupply	N_2 Gas	-	440
	N_2 Tanks	2	480
	O_2 Gas	-	1320
	O_2 Tanks	6	1440
	Carriers	2[1]	1340
	Carrier/Pallet Hookup/Debris Shields	8	800
	Sub-total	-	5820
Repressurization & 45-Day Skip Cycle	N_2 Gas	-	440
	N_2 Tanks	2	480
	O_2 Gas	-	660
	O_2 Tanks	3	720
2-Fault Tolerance	N_2 Gas	-	220
	N_2 Tanks	1[2]	240
	O_2 Gas	-	220
	O_2 Tanks	1[2]	240
	Carriers	2[1]	1340
	Carrier/Pallet Hookup/Debris Shields	7	700
	Sub-total	-	5260
Assembly Phase Element Leakage	N_2 Gas	-	660
	N_2 Tanks	3	720
	O_2 Gas	-	220
	O_2 Tanks	1	240
	Carriers	1[1]	670
	Carrier/Pallet Hookup/Debris Shields	4	400
	Sub-total	-	2910
	Total		13,990

1 Each carrier holds 4 Tanks
Carriers = 11' x 4' x 7' = 308ft^3
Tank = 38" diameter = 15 ft^3

2 1 additional N_2 & O_2 Tank each required to implement 2-Fault Tolerance

3.3 Bus-1 Functionality

A purpose of this study was to help define the needed functionality that the Bus-1(s) would provide in order to assist in the assembly and operation of the international Space Station. For this first iteration, the Bus-1 functionality was assumed to be as close as possible to currently existing "off the shelf" hardware functionality. For manifesting purposes, the buses used in this Tier 2 assembly sequence were all identical although the first Bus-1 delivered to orbit is the only one that needs to have full spacecraft functionality. The remaining buses delivered to orbit would only require propulsion tank/thruster functionality. These buses could be modified to have a larger propellant storage capability than the first Bus-1 in order to minimize potential propellant shortages.

Data Sources

The following documents and studies were used to obtain technical information on the Bus-1 vehicle:

1. *Bus 1 Technical Data Book* - July 1993; Lockheed Missiles and Space Company
2. *Bus 1 Implementation Concept for Space Station Alpha* - 25 November 1993; Lockheed Missiles and Space Company
3. *Bus 1 Study Review, FY94 & FY95* - September 2, 1994; Lockheed

Configuration (see figure 3.3-1)

- Diameter: 159 in.
- Length: 105 in.
- 24,000 lb (including propellant)
- 11,660 lb propellant capacity
- ==> 12,340 lb of hardware, software, etc.

Data Management System

- Approximately 1.4 MIPS aggregate/CPU box (3 processors)
- 96K word addressable memory - 24 bit word length
- 3072 instrument channels for 3 RDMs
- 768 discrete outputs for 3 RDMs

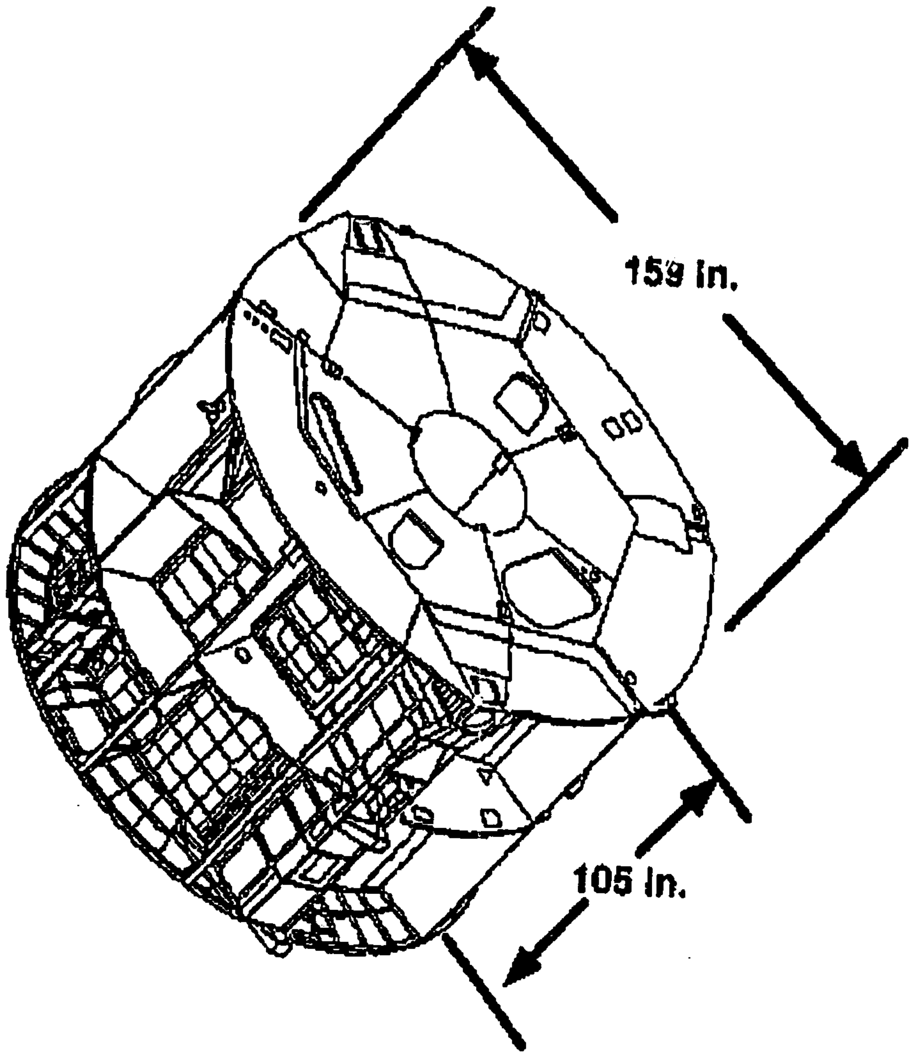


Figure 3.3-1 Bus-1 configuration.

Attitude Reference System

- 9 rate gyros provide attitude reference knowledge
  - 5 active at any time (4 spare)
  - 0.03 deg/hr drift stability
- 3 scanning star sensors provide periodic updates to the attitude reference system
  - <5 arc-seconds accuracy
  - 4.8 deg FOV
- 2 3-axis magnetometers
  - "Secondary attitude reference based on magnetometer and rate gyros. Corrects primary reference if primary reference is not healthy."

- Control Sun Sensor
    - "Can provide attitude correction in sun pointing attitude only."
    - "Used as back-up only when star processing and magnetic reference algorithms are not healthy."
- "Ephemeris determination is accomplished by use of the Bus-1 Position Reference Subsystem which utilizes a single channel GPS receiver and ground algorithms."

Momentum Management

- 6 - single-axis CMGs used to maintain station attitude until activation of Station CMGs
- Each CMG provides 1700 ft-lb-sec of angular momentum capability
- System Spherical Momentum Capability
    - 6 CMGs (3H = 5100 ft-lb-sec)
    - 5 CMGs (2.4H = 4080 ft-lb-sec)
    - 4 CMGs (1.6H = 2720 ft-lb-sec)
- Geometric momentum capability is up to 9250 ft-lb-sec in some directions (capability not currently used)

Propulsion System

Information pertaining to the exact thruster layout of existing Bus-1 hardware was not available. A Space Station specific thruster layout that was designed to reduce plume impingement on the station radiators and other surfaces was utilized. Figure 3.3-2 shows the attitude thrusting directions for both Buses on the Stage 36 station configuration. The cant angle of the thrusters minimizes plume impingement for aft Bus-1 on station subsystems such as the TCS radiators. The zenith Bus-1 attitude thruster plane is also shown in this figure. For Stages 10-21, the zenith Bus-1 is located even farther away from the station core body, due to the P6 truss segment being incorporated into the z-axis truss extension. Figure 3.3-3 demonstrates the Bus-1 reboost engine gimbal range in relation to the station solar arrays and TCS radiators. The two Bus-1 reboost engines are oriented along the station body x-axis and are capable of gimbaling ±10 degrees. There appears to be sufficient clearance between the reboost thrust direction and station components. The resulting thruster plume effects should be minimal.

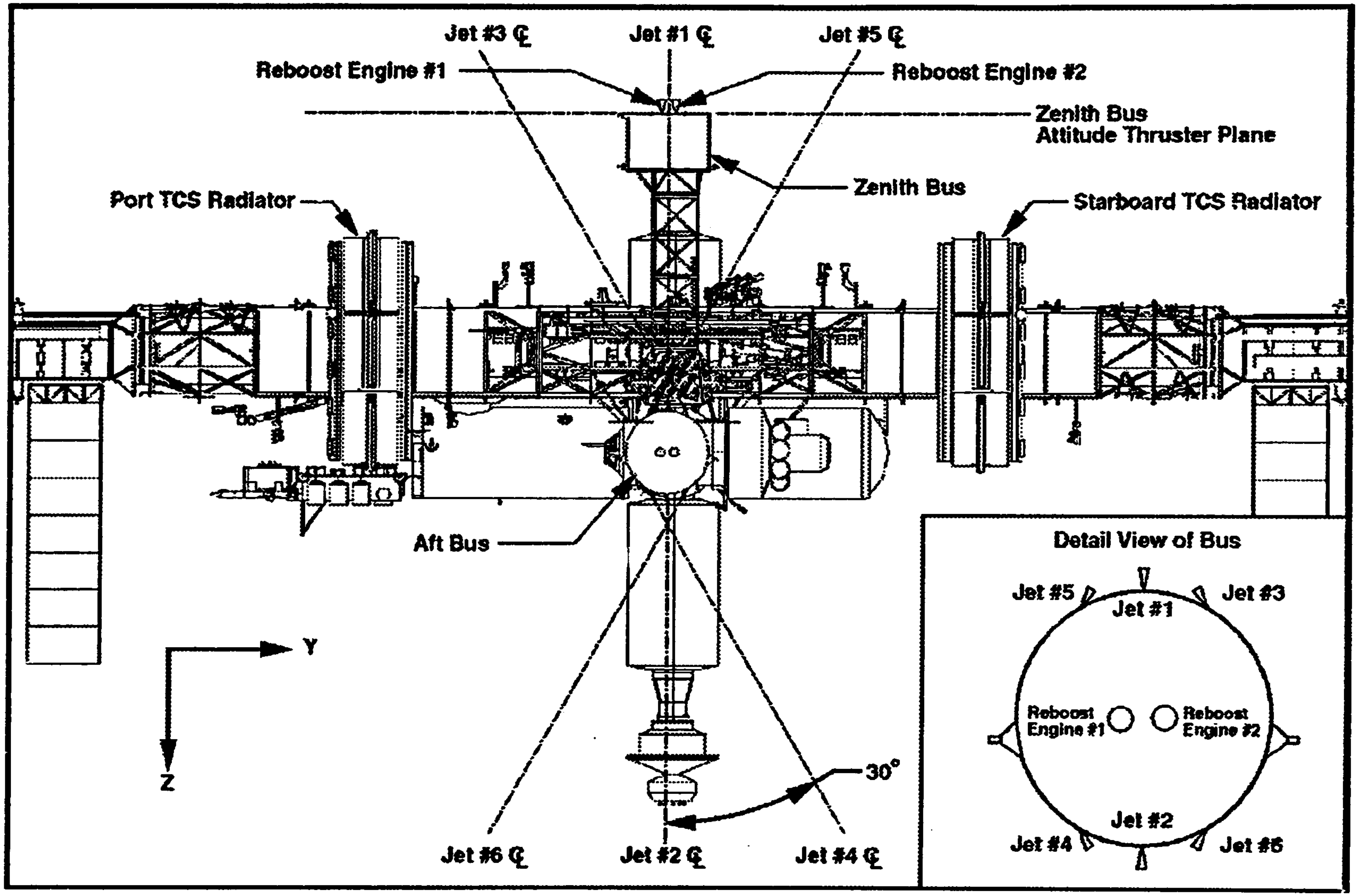


Figure 3.3-2 X-axis view of aft and zenith bus thruster configuration.

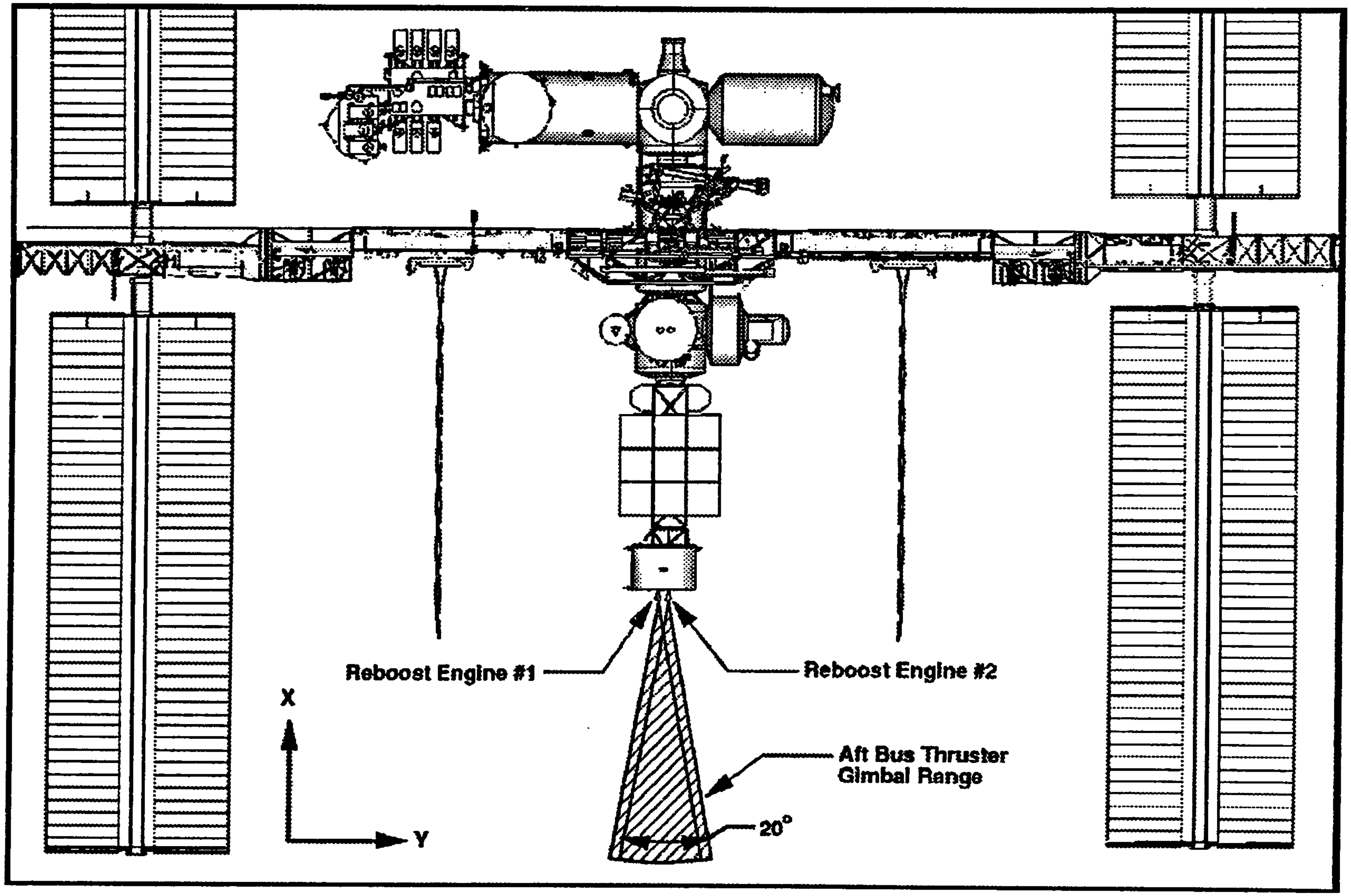


Figure 3.3-3 Z-axis view of aft and zenith bus thruster configuration.

It was assumed that the reaction control systems of the aft and zenith buses were not coupled together which leads to worst case fuel estimates for station maneuvers. The higher fuel consumption results from the a small roll moment arm on the aft Bus-1 and a small yaw moment arm on the zenith Bus-1.

- Bipropellant system MMH/N_2O_4
- 2 main thrusters operating at 140 lbf to 300 lbf (±10 degree gimbal angle)
  - ISP = 295 sec
  - Total impulse per engine = 3,000,000 lbf-sec
  - Minimum impulse bit = 3.5 lbf sec
  - 247 W power requirement
- 2 sets of attitude control thrusters (total of 12) operating at 10 lbf to 22 lbf
  - Avg. ISP = 265 sec (pulse mode); 280 sec steady state (>10 sec.)
  - Total impulse per thruster = 134,000 lbf-sec
  - Min. pulse width = 0.1 sec.

Power System

- Maximum power = 3200 W of 28 Vdc (nominal) power (@51.6 deg.)
- 6 NiH_2 (22 cell) batteries with 15 amp-hours rating at BOL (90 amp-hours total)
- 112 lb
- GaAs solar cells on a Germanium substrate are mounted to the stinger

Thermal Control System

- Passive:
  - Tapes, paints, MLI
- Active:
  - Propellant subsystem, battery variable conductance heat pipes, GMA, GPA/GMA gyros and star sensors utilize heaters.

Communications System

- S-Band transponder (dual channel)
- 1 Kbps UP, 32 Kbps Down (direct to ground)
- Uses the Space Ground Link Subsystem (SGLS) with USAF Ground Stations
- Four switched antennas
- 26 lb

Launch Packaging

The first Bus-1 launched requires an attached extender truss which has several key functions. The primary function is to move the reaction control jets and reboost engines as far as possible from space station systems to minimize plume impingement. Another function is to provide space to attach solar arrays and a power data grapple fixture. The extender truss also acts as an interface between the Bus-1 and the station attach point. Figure 3.3-4 depicts two options for the aft Bus-1/extender which is the first element launch in this sequence. The Long Extender Option assumes that the outfitting of the last orbiter with the Orbital Docking System (ODS) has been delayed past FEL. This allows over 8 feet of additional space in the cargo bay for a longer extender truss resulting in almost no plume impingement. Delaying the installation of the ODS could have significant schedule impacts on the remainder of the assembly sequence thus the Short Extender Option was used in this iteration of the analysis. All analysis assumed the Short Extender Option with the exception of the robotic/kinematic analysis which assumed the Long extender Option as a worst case scenario. Composite Shuttle payload center of mass calculations are TBD but should be within operational constraints due to the large amount of mass associated with the Bus-1 in the aft end of the Shuttle.

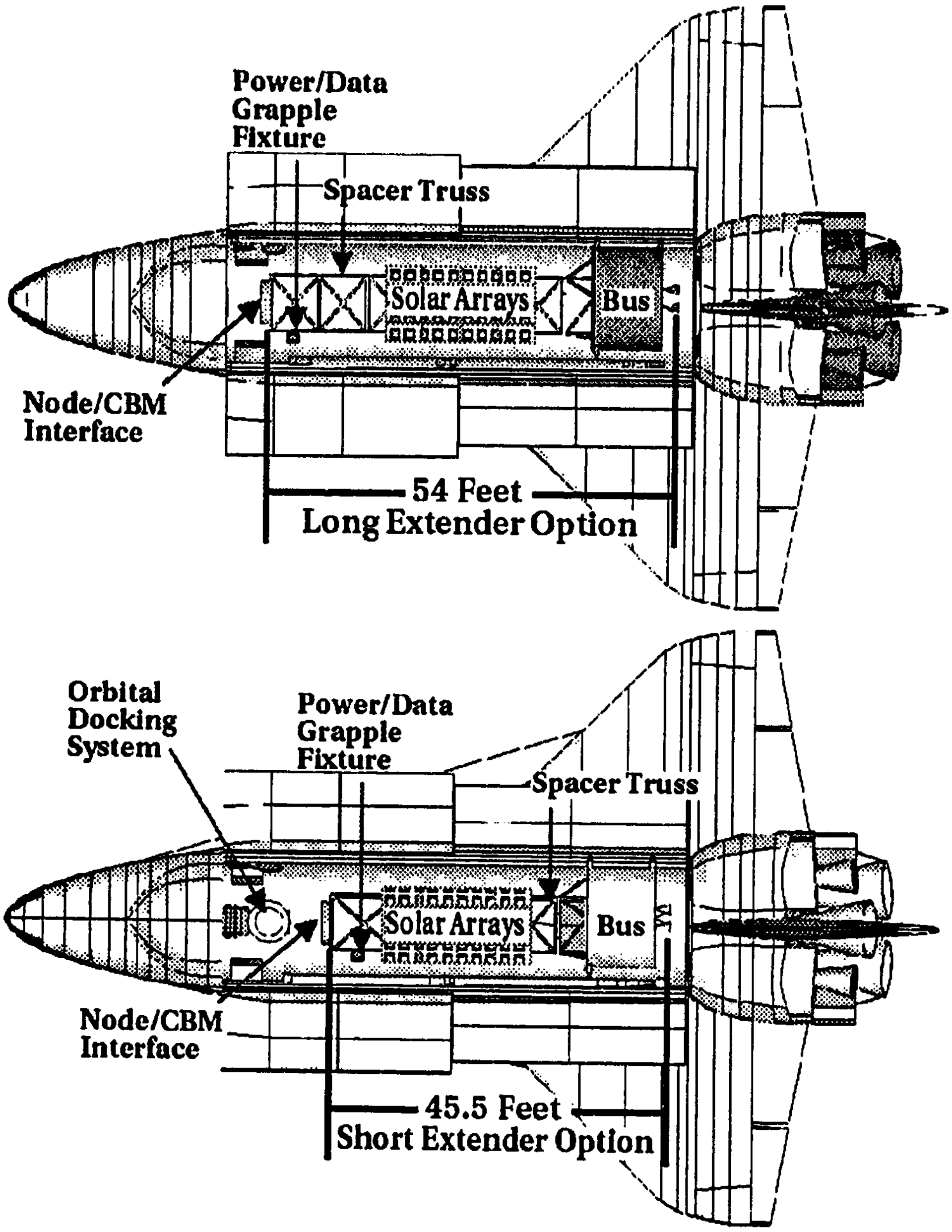


Figure 3.3-4 Bus-1 packaged in Shuttle payload bay with short and long truss extender options.

4. Assembly Sequence

The Tier 2 Assembly Sequence was provided to LaRC Spacecraft and Sensors Branch (SSB) by JSC International Space Station Program Office. The LaRC Tier 2 Data book team made slight modifications to the sequence in order to reduce EVA assembly requirements. The flight names were renamed in effort to maintain consistency with the baseline (9/94) ISSA Assembly Sequence. For example, the centrifuge comes up on flight 14A in the baseline, therefore it was called flight 14A in this alternate assembly sequence. "New" flights were named after the previous flight with an + sign as an identifier that this was an additional flight over that in baseline. These additional flights were necessary to provide additional EVA time to assemble the station. The baseline program has crew on-board Station early in the sequence, and uses this crew to provide EVA when the Shuttle is not present. The stage numbers are used to identify the sequential order of the flights.

Table 4-1 provides the Tier 2 Assembly Sequence Summary. The table provides the stage number, the launch date used for analysis, the elements delivered to Station, the assembly altitude, net mass to orbit, Shuttle mission duration, the number of Shuttle crew, and the scheduled EVA missions for each assembly flight. The detailed Shuttle manifests for each assembly flight are provided in their stage specific Section 5.1.

The mass properties of Stages 1 through Stage 36 are listed in table 4-2. Table 4-3 lists the mass properties of Stages 1 through 36 with the Shuttle attached. The tables include mass, center of gravity (measured in meters with respect to the origin located at the center of the S0 truss segment), principal to body axis Euler angles, and the principal moments of inertia. Stage characterization trend analyses are presented in Section 6.

Table 4-1 Tier 2 Assembly Sequence Manifest

	Launch Date	Flight Name	Delivered Elements	Altitude (Nm)	Mass to Orbit (lbs)	Mission Duration (days)	STS crew	Scheduled EVAs
1	2/98	1A	Bus-1, Spacer	210	31221	7	5	0
2	4/98	2A	Node 1 (2 storage racks), PMA3, PMA2	205	27631	7	5	2
3	6/98	3A	Z1 truss, CMGs, Ku-band, HP Gases, EVAS (Spacelab Pallet)	200	14004	9	5	3
4	9/98	4A	P6, PV Array (4 battery sets) / EATCS radiators, S-band	190	32956	8	5	2
5	11/98	5A	Lab (4 Lab Sys racks)	205	29765	9	5	3
6	12/98	6A	1 Storage, 7 Lab Sys racks (on MPLM), UHF, SSRMS (on Spacelab Pallet)	215	12852	12	5	3
7	2/99	UF-1	ISPRs (on MPLM)	215	15000	12	7	0
8	4/99	7A	Airlock, HP gas (on Spacelab Pallet)	215	21609	9	5	2
9	6/99	8A	S0, MT, GPS, Umbilicals, A/L Spur	215	30205	7	5	2
10	8/99	Bus	Bus-1, spacer	215	28256	9	5	3
11	10/99	UF-2	ISPRs, 2 Storage Racks (on MPLM), MBS	215	5615	12	7	1
12	12/99	9A	S1 (3 rads), TCS, CETA (1), S-band	215	31026	7	5	2
13	2/00	10A	Node 2 (4 DDCU racks), Cupola	215	27359	12	5	4
14	4/00	11A	P1 (3 rads), TCS, CETA (1), UHF	215	30720	9	5	3
15	6/00	UF-3	ISPRs, 1Storage Rack (on MPLM)	215	12890	12	7	0
16	8/00	1J/A	JEM ELM PS (5 JEM Sys, 2 ISPR, 1 Storage Rack), 2 O2 tanks (on ULC), SPDM	220	22810	10	7	6
17	10/00	12A	P3/4, PV Array (4 battery sets), 2 ULCAS	220	32781	8	5	2
18	12/00	12A+	P5, P4/P5 MT/CETA Rails, P4 PV Battery Sets (2) 16-day EDO Pallet	230	6083	15	7	7
19	2/01	UF-4	ISPRs (on MPLM)	230	13000	12	7	0
20	4/01	BF-1	Bus-1	230	25000	7	5	0
21	6/01	13A	S3/4, PV Array (4 battery sets), 4 PAS	230	31994	8	5	2
22	8/01	13A+	S4 PV battery sets (2), S4 & P6 MT/CETA rails (on ULC), 16-day EDO Pallet	230	2556	15	7	6
23	10/01	UF-5	ISPRs on (MPLM), Attached Payloads (on ULC)	230	9000	12	7	0
24	12/01	1J	JEM PM (3 JEM Sys racks), JEM RMS	230	30864	9	5	2
25	2/02	2E	1 APM Storage, 3 U.S. Storage, 7 JEM racks (on MPLM), S5	230	13229	9	5	1
26	4/02	UF-6	ISPRs (on MPLM)	230	13000	12	7	0
27	6/02	2J/A	JEM EF, ELM-ES, P6 PV battery sets (2)(on ULC)	230	14540	7	5	1
28	8/02	15A	S6, PV Array (4 battery sets)	230	26886	9	5	3
29	10/02	BF-2	Bus-1	230	25000	7	5	0
30	12/02	UF-7	ISPRs, 1Storage Rack (on MPLM)	230	14390	12	7	0
31	2/03	14A	Centrifuge	230	24255	9	7	1
32	4/03	1E	APM (5 Sys, 1 Storage, 5 ISPR racks)	230	26467	9	5	1
33	6/03	16A	Hab (6 Hab racks)	230	27502	8	5	2
34	8/03	17A	1 Lab Sys, 8 Hab Sys racks (on MPLM), S6 PV battery sets (2)(on ULC)	230	10913	8	5	0
35	10/03	18A	CTV #1	230	24255	8	5	0
36	12/03	19A	3 Hab Sys, 11 U.S. Storage racks (on MPLM)	230	14402	7	7	0

Table 4-2 Tier 2 Space Station Mass Properties

STAGE	MASS(kg)	CENTER OF GRAVITY (m)			EULER ANGLES (deg)			PRINCIPAL MOMENTS OF INERTIA (kg-m**2)		
		X	Y	Z	PSI	THETA	PHI	Ixx	Iyy	Izz
1-1A	1.42E+04	-18.66	-0.294	4.839	-2.571	-0.512	-1.142	2.91E+04	1.28E+05	1.27E+05
2-2A	2.67E+04	-12.12	-0.156	4.976	-1.287	1.074	-0.356	6.45E+04	1.49E+06	1.47E+06
3-3A	3.76E+04	-10.69	-0.111	4.351	-1.465	-3.459	4.278	1.67E+05	1.83E+06	1.76E+06
4-4A	5.23E+04	-8.878	-0.056	0.75	-10.63	-41.18	13.3	2.04E+06	4.13E+06	3.95E+06
5-5A	6.58E+04	-6.547	0.002	1.667	-1.58	-14	-0.8	3.07E+06	5.88E+06	4.78E+06
6-6A	7.17E+04	-5.818	-0.087	1.821	-0.74	-8.34	-2.26	3.18E+06	6.36E+06	5.21E+06
7-UF1	7.86E+04	-5.158	-0.079	2.085	-0.82	-3.72	-2.2	3.28E+06	6.82E+06	5.58E+06
8-7A	8.83E+04	-5.108	0.386	2.385	-1.32	-3.42	2.54	3.53E+06	6.90E+06	5.76E+06
9-8A	1.02E+05	-4.365	0.347	2.092	-1.08	-6.08	3.59	3.78E+06	7.39E+06	6.34E+06
10-BUS	1.15E+05	-4.391	0.272	-0.459	-0.96	3.41	1.9	9.81E+06	1.34E+07	6.33E+06
11-UF2	1.19E+05	-4.307	0.32	-0.352	-1.31	4.43	2.08	9.90E+06	1.36E+07	6.46E+06
12-9A	1.28E+05	-3.64	1.765	-0.522	-22.97	1	4.28	1.18E+07	1.40E+07	8.98E+06
13-10A	1.40E+05	-2.628	1.586	-0.048	-9.8	-18.02	4.7	1.27E+07	1.58E+07	1.06E+07
14-11A	1.54E+05	-2.499	0.218	-0.045	9.45	-19.07	6.38	1.59E+07	1.62E+07	1.40E+07
15-UF3	1.54E+05	-2.49	0.219	-0.063	10.01	-19.32	6.42	1.59E+07	1.62E+07	1.40E+07
16-1J/A	1.62E+05	-1.894	0.208	-0.024	4.29	-36.69	5.45	1.63E+07	1.73E+07	1.48E+07
17-12A	1.77E+05	-1.753	-2.204	-0.003	-5.3	-38.1	1.9	2.82E+07	1.77E+07	2.71E+07
18-12AP	1.80E+05	-1.69	-2.45	-0.021	-5.47	-38.52	3.22	2.99E+07	1.83E+07	2.86E+07
19-UF4P	1.80E+05	-1.796	-2.449	-0.025	-6.49	-44.02	4.34	3.00E+07	1.85E+07	2.88E+07
21-13A	1.97E+05	-1.394	-3.317	1.356	0.09	10.81	-0.36	4.42E+07	2.03E+07	4.58E+07
22-13AP	1.97E+05	-1.391	-3.276	1.36	-1.06	-1.67	-1.03	6.52E+07	1.47E+07	7.12E+07
24-1J	2.12E+05	-0.655	-3.935	1.658	-2.69	3.85	-1.01	6.61E+07	1.65E+07	7.35E+07
25-2E	2.13E+05	-0.65	-3.643	1.649	-2.53	3.76	-0.88	6.85E+07	1.65E+07	7.58E+07
27-2J/A	2.26E+05	-0.07	-4.129	1.827	-3.7	5.96	-0.67	7.00E+07	1.79E+07	7.84E+07
28-15A	2.40E+05	-0.049	-1.366	1.737	-2.53	5.61	0.27	1.01E+08	1.89E+07	1.08E+08
30-UF7P	2.40E+05	-0.07	-1.347	1.739	-2.32	5.67	0.27	1.00E+08	1.89E+07	1.09E+08
31-14A	2.50E+05	0.34	-1.288	1.597	-2.24	3.23	0.39	1.01E+08	2.00E+07	1.10E+08
32-1E	2.66E+05	0.935	-0.849	1.788	-1.54	6.01	0.13	1.02E+08	2.15E+07	1.12E+08
33-16A	2.78E+05	0.634	-0.812	2.249	-1.58	1.86	0.16	1.03E+08	2.32E+07	1.12E+08
34-17A	2.82E+05	0.565	-0.802	2.364	-1.6	0.82	0.17	1.03E+08	2.36E+07	1.12E+08
35-18A	2.93E+05	0.415	-0.771	2.956	-1.63	-5.73	0.26	1.06E+08	2.64E+07	1.13E+08
36-19A	2.95E+05	0.468	-0.766	2.958	-1.62	-5.55	0.24	1.06E+08	2.65E+07	1.13E+08

Table 4-3 Tier 2 Space Station Mass Properties with Shuttle Attached

STAGE	MASS (KG)	CENTER OF GRAVITY (m)			EULER ANGLES (deg)			PRINCIPAL MOMENTS OF INERTIA (kg-m**2)		
		X	Y	Z	PSI	THETA	PHI	Ixx	Iyy	Izz
5-5A	1.58E+05	1.798	0.012	7.143	-0.39	16.34	-0.75	6.42E+06	2.68E+07	2.29E+07
6-6A	1.64E+05	3.289	-0.049	10.483	-0.71	-37.71	0.17	2.91E+07	3.62E+07	9.59E+06
7-UF1	1.71E+05	3.226	-0.047	10.258	-0.7	-37.52	0.16	2.93E+07	3.65E+07	9.66E+06
8-7A	1.81E+05	2.797	0.179	9.962	0.77	-38.23	-0.78	3.03E+07	3.74E+07	9.92E+06
9-8A	1.95E+05	2.633	0.173	9.279	0.83	-36.9	-0.71	3.16E+07	3.87E+07	1.03E+07
10-BUS	2.07E+05	2.186	0.142	7.423	1.03	-28.88	-0.15	4.19E+07	5.02E+07	1.16E+07
11-UF2	2.12E+05	2.092	0.172	7.314	1.06	-28.94	-0.19	4.21E+07	5.06E+07	1.18E+07
12-9A	2.26E+05	1.978	0.997	6.864	-0.47	-28.56	-2.46	4.53E+07	5.14E+07	1.44E+07
13-10A	2.38E+05	4.323	0.931	6.76	1.52	-39.63	-2.72	5.32E+07	6.16E+07	1.67E+07
14-11A	2.52E+05	4.02	0.13	6.387	2.06	-39.82	-0.24	5.7[illegible]E+07	6.30E+07	1.99E+07
15-UF3	2.59E+05	3.918	0.154	6.194	9.29	-39.69	-0.34	6.21E+07	6.34E+07	2.43E+07
16-1JA	2.60E+05	4.207	0.126	6.213	1.99	-39.7	-0.24	5.73E+07	6.34E+07	2.03E+07
17-12A	2.74E+05	3.967	-1.449	5.876	-8.3	-39.35	6.86	7.03E+07	6.45E+07	3.22E+07
18-12AP	2.78E+05	3.935	-1.592	5.793	-8.21	-39.23	7.36	7.23E+07	6.56E+07	3.41E+07
19-UF4P	2.78E+05	3.901	-1.595	5.81	-8.59	-39.6	7.29	7.26E+07	6.61E+07	3.43E+07
21-13A	2.93E+05	3.751	0.082	5.504	-0.17	-39.15	0.34	8.73E+07	6.59E+07	4.88E+07
22-13AP	2.95E+05	3.808	-2.194	6.395	9.1	-38.1	0.4	7.62E+07	5.80E+07	1.08E+08
24-1J	3.09E+05	4.052	-2.697	6.346	11.63	43.12	-3.87	7.72E+07	5.85E+07	1.09E+08
25-2E	3.11E+05	4.042	-2.504	6.324	9.26	43.23	-3.53	7.91E+07	5.90E+07	1.12E+08
27-2JA	3.24E+05	4.311	-2.887	6.265	7.01	42.96	-4.17	8.08E+07	5.96E+07	1.13E+08
28-15A	3.38E+05	4.098	-0.974	6.024	-2.42	43.6	-1.8	1.10E+08	6.20E+07	1.44E+08
30-UF7P	3.37E+05	4.145	-0.961	6.001	-2.4	43.6	-1.76	1.10E+08	6.20E+07	1.43E+08
31-14A	3.48E+05	4.251	-0.931	5.791	-2.37	43.88	-1.71	1.11E+08	6.30E+07	1.44E+08
32-1E	3.59E+05	4.626	-0.634	5.736	-1.59	44.41	-1.25	1.11E+08	6.25E+07	1.44E+08
33-16A	3.76E+05	4.228	-0.603	5.951	-1.75	43.17	-1.34	1.13E+08	6.50E+07	1.45E+08
34-17A	3.79E+05	4.076	-0.598	6.004	-1.78	43.03	-1.37	1.14E+08	6.54E+07	1.45E+08
35-18A	3.91E+05	3.84	-0.581	6.333	-1.86	43.82	-1.53	1.16E+08	6.76E+07	1.45E+08
36-19A	3.88E+05	4.041	-0.587	6.348	-1.77	44.58	-1.53	1.16E+08	6.69E+07	1.44E+08

5. Flight Characterization by Assembly Stage

5.1 Stage 1 Flight Characterization

5.1.1 Stage 1 - Flight 1A Shuttle Flight Manifest

The Space Station assembly sequence begins with the launch of Bus-1. Table 5.1.1-1lists the Shuttle Flight Manifest for Stage 1 - Flight 1A. In the first section of the table, the first column lists the station hardware launched, the second column gives the hardware mass, and the third column lists any additional Flight Support Equipment (FSE) required to launch the Station hardware but not left on-orbit. The total mass of the station hardware to orbit is 31221 lbs. The second section of table 5.1.1-1 shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 31296 lbs to 217 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission f.:ght margin of 75 lbs.

5.1.2 Stage 1 Configuration

An isometric picture of Stage 1 is depicted in figure 5.1.2-1. Refer to figure 5.1.2-2 for the front, side, top and isometric views of the Stage 1 configuration.

5.1.3 Flight 1A Assembly Operations Description

Bus-1 and a PV array mounted on the spacer truss are launched. A CBM (Node 1 truss adapter) is mounted on end of truss to connect to Node 1 on Flight 2A.

The SRMS removes the Bus-1 assembly from the Shuttle payload bay. The Bus-1 is oriented aft, spacer truss is forward. Flight mode is arrow and no reboost required until next assembly flight. The assembly altitude will be such that Stages 1, 2 & 3 will meet Flight 4A's assembly altitude requirements.

<u>System Resource/Functionality</u>

First element launch provides the Bus-1 capabilities documented in Section 3.3.

Table 5.1.1-1 Stage 1 - Flight 1A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
Bus -1	25000	
Bus PV	220	
batteries	840	
Node 1 to truss adapter	220	
Spacer	4941	
subtotal	**31221**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		300
Variable Integrated Hardware		0
Variable Shuttle Consumables		-55
Food and Gear (-55 lbs/day > 6)	55	
Middeck Lockers		-160
Generic Integrated Hardware		-5474
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFERs (2)	200	
Misc integration hardware	118	
Attach Hardware	990	
	5474	
Weight Growth Reserve		-1000
Total Shuttle Lift Capability		**31296**

Mission Flight Margin		**75**

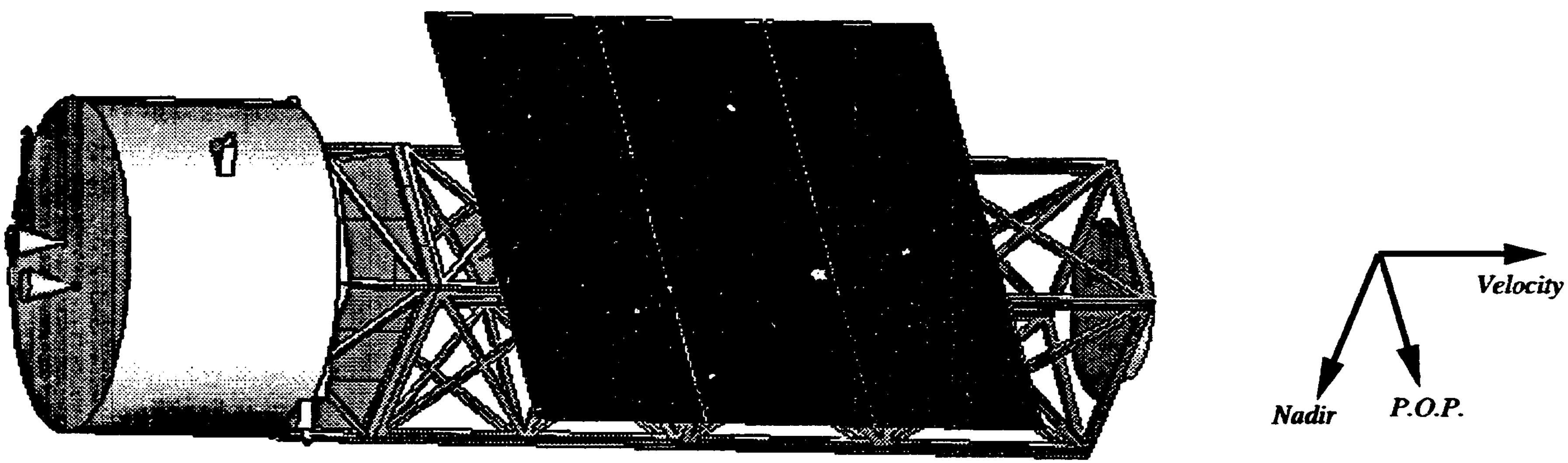


Figure 5.1.2–1 Stage 1 Configuration

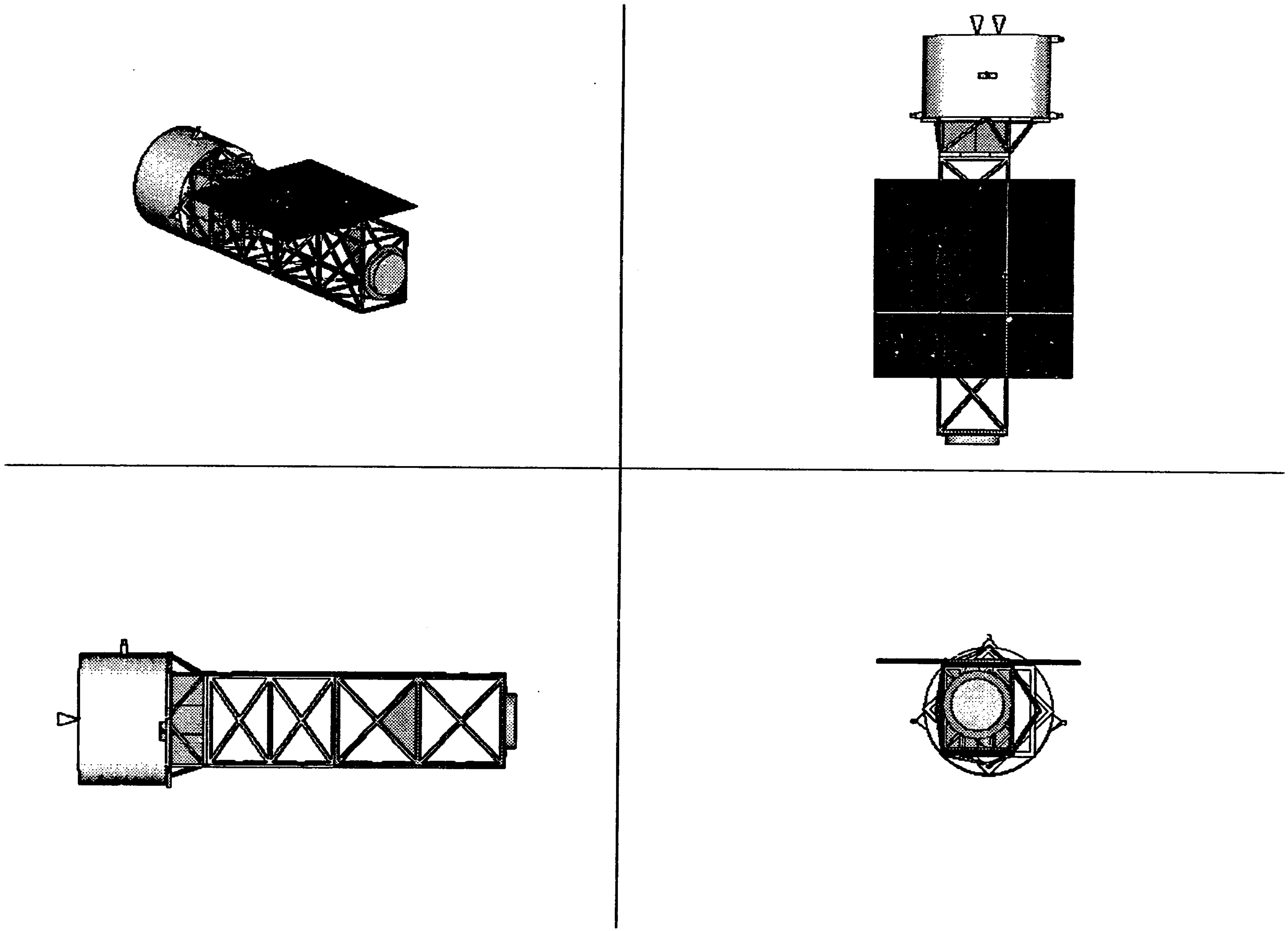


Figure 5.1.2–2 Stage 1 Configuration

5.1.4 Stage 1, Flight 1A Performance Characteristics

Stage 1, Flight 1A is initially launched to an altitude of 217 n.mi. Nominal launch date is February, 1998. Nominal flight attitude is arrow. The configuration is allowed to decay until Stage 2 is launched in April, 1998.

There are no microgravity requirements for Stage 1.

Table 5.1.4-1 summarizes the lifetime characteristics of Stage 1 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 56.5 lbs/ft^2. No reboost was performed for this stage as it is required to decay to 213 n.mi. in order to rendezvous with Stage 2. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.1.4-1 Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
217	N/A	N/A	11,600	N/A	386

The control characteristics of Stage 1 under design atmosphere conditions are displayed in figure 5.1.4-1. Table 5.1.4-2 summarizes the control characteristics depicted in the plots. Control requirements for Stage 1 require only a small fraction of the capability of the bus CMGs.

Table 5.1.4-2 Control Characteristics Summary

Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
5.0 degrees	0.0 degrees	-1.25 degrees	± 2.0 degrees	< 120 N-m-s

5.1.5 Issues and Concerns

None.

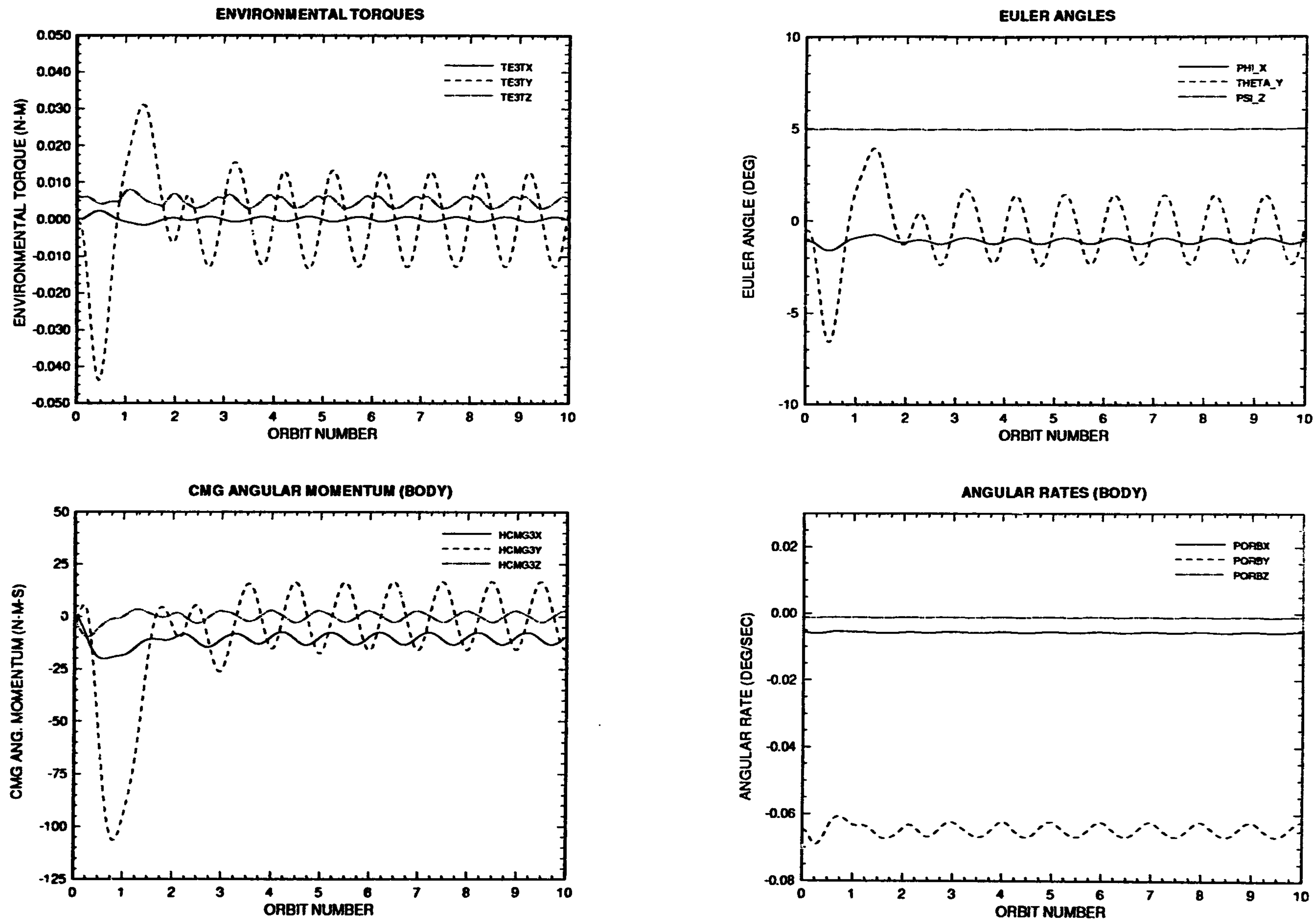


Figure 5.1.4-1 Stage 1 control plots without Shuttle attached.

5.2 Stage 2 Flight Characterization

5.2.1 Stage 2 - Flight 2A Shuttle Flight Manifest

The second assembly flight delivers Node 1, equipped with two stowage racks and the Pressurized Mating Adapters 2 and 3 (PMA-2, PMA-3). Table 5.2.1-1 lists the Shuttle Flight Manifest for Stage 2 - Flight 2A. The total mass of the station hardware to orbit is 27631 lbs. The second section of table 5.2.1-1 shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 30338 lbs to 213 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 2707 lbs.

5.2.2 Stage 2 Configuration

Figure 5.2.2-1 displays the isometric view of Stage 2 after the Shuttle departs and the scheduled assembly is completed. Figure 5.2.2-2 shows the front, side, top and isometric views of Stage 2 with the Shuttle attached.

5.2.3 Flight 2A Assembly Operations Description

PMA2 and PMA3 are launched preattached to Node 1. The SRMS grapples a Flight Releasable Grapple Fixture (FRGF) on PMA-2, removes Node1/PMAs element from the payload bay, and pitches it 90 degrees relative to the Shuttle. The operation is completed when Node 1, via PMA2, is attached to the Shuttle docking system (ODS). The SRMS removes PMA3 from the Node 1 axial port and attaches it to Node 1 nadir port, which is located in the +x-axis (shuttle coordinate) direction. The Shuttle then performs an R-bar approach to Stage 1. The SRMS grapples the Bus-1 assembly at the Power Data Grapple Fixture (PDGF) located on the stinger and attaches it to the common berthing mechanism on the Node 1 axial port.

Following separation, the Stage 2 flight mode is solar inertial with the body x-axis (i.e., along the Bus-1/Node 1 assembly) in the plane of the orbit perpendicular to the sun line.

System Resource/Functionality

Stage 1 functionality, plus:

- Shuttle pressurized access via PMA2
- Node 1 remains in "keep-alive" state

Resources Available:	*Power:*	*3200 W*	*(Bus-1)*
	Thermal:		
	EVA:	*24 crew-hours*	
Resources Required:	*Power:*	*868 W*	*(U.S. Housekeeping)*
		1600 W	*(Bus-1 Housekeeping)*
	Thermal:	*TBD*	
	EVA:	*17:20 crew-hours*	

Table 5.2.1-1 Stage 2 - Flight 2A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
Node 1	19572	
US Stowage Rack 3	1198	
APM/US Stowage Rack 4	1128	
PMA2	2867	
PMA3	2867	
subtotal	**27631**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		700
Variable Integrated Hardware		0
Variable Shuttle Consumables		-1183
Food and Gear (-55lbs/day over 6)	55	
5th N2 tank	128	
OMS	1000	
	1183	
Middeck Lockers		-390
Generic Integrated Hardware		-5474
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFERs (2)	200	
Misc integration hardware	118	
Attach Hardware	990	
	5474	
Weight Growth Reserve		-1000
Total Shuttle Lift Capability		**30338**

Mission Flight Margin		**2707**

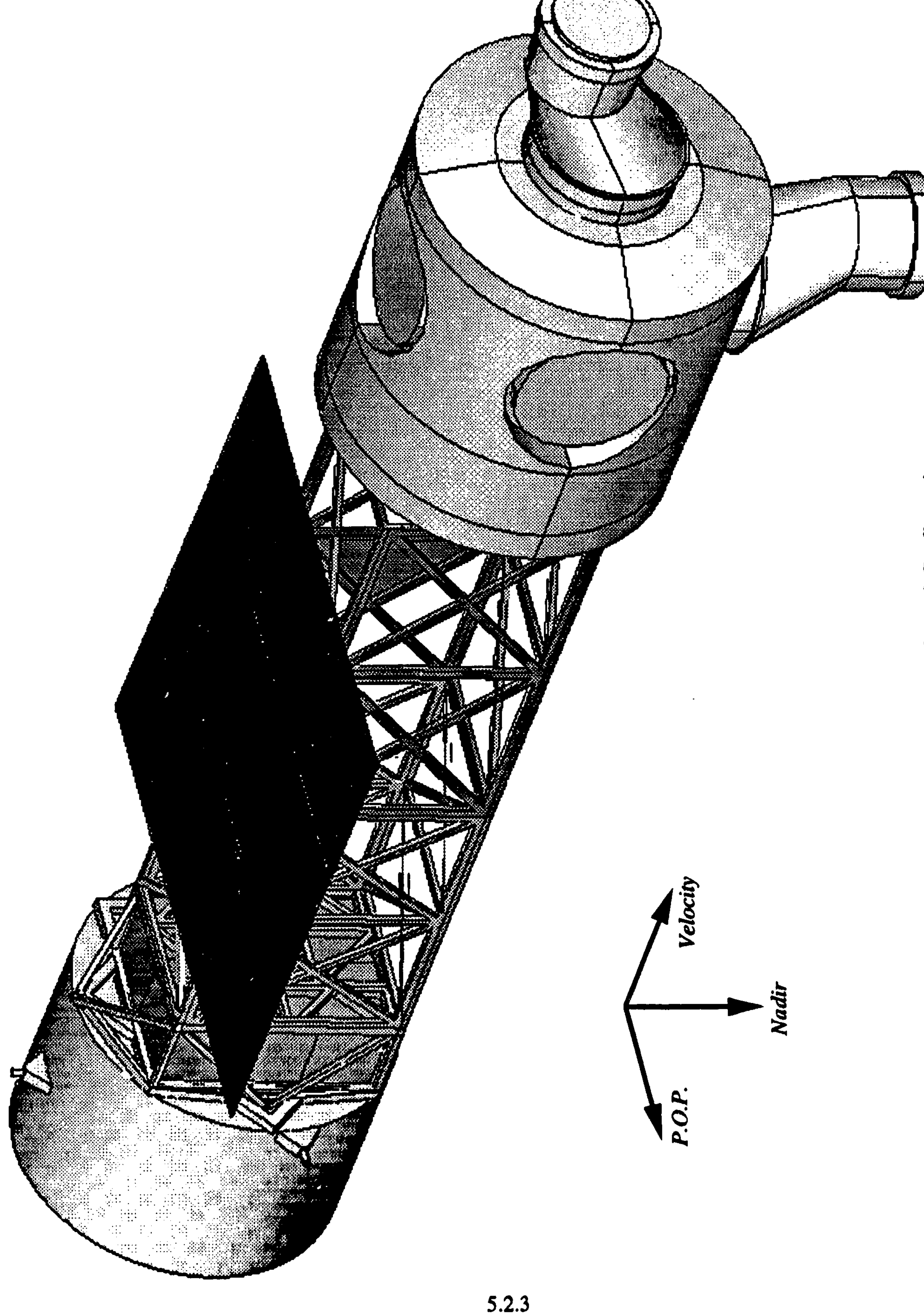


Figure 5.2.2-1 Stage 2 Configuration

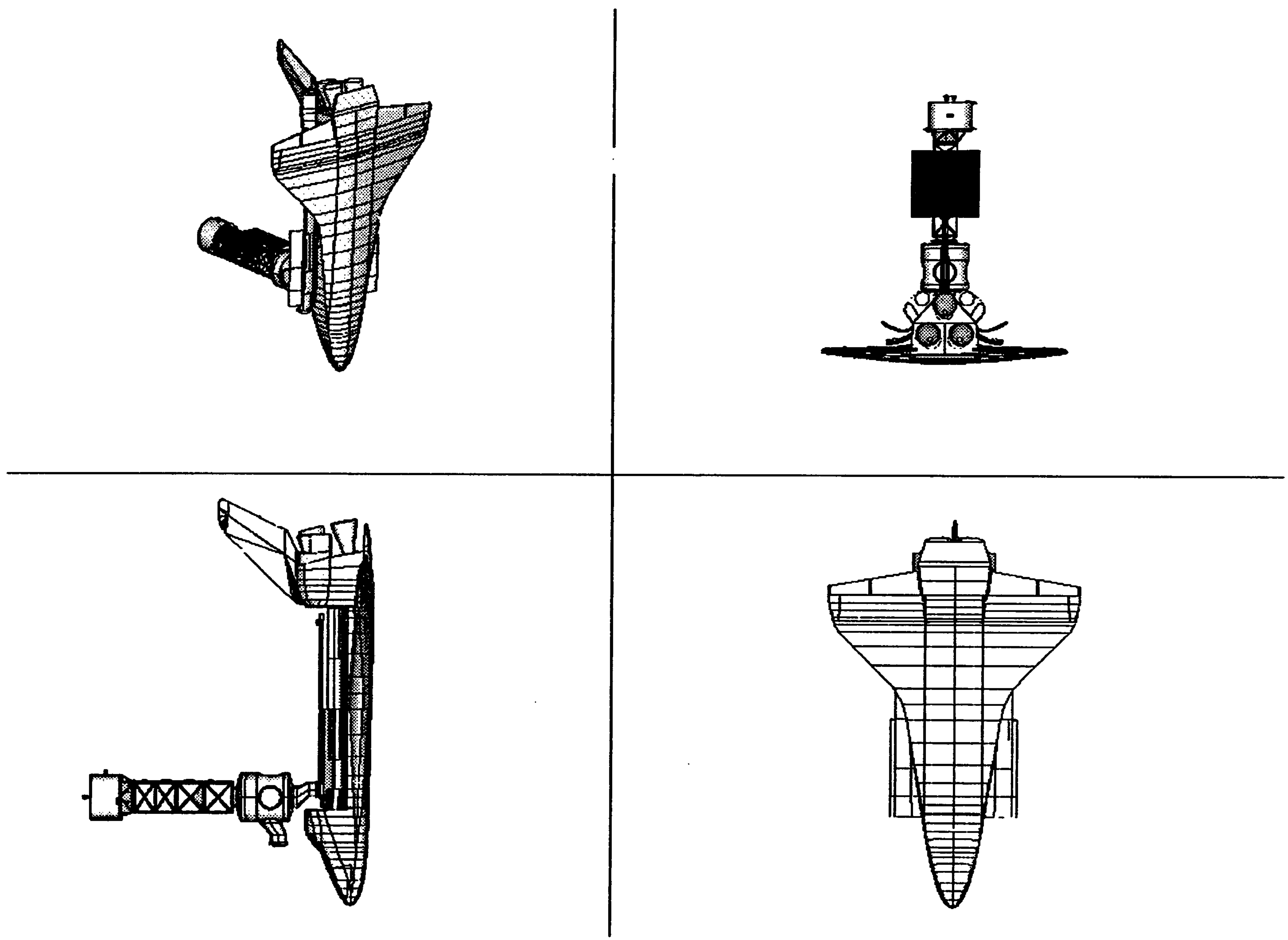


Figure 5.2.2-2 Stage 2 Configuration with Shuttle

5.2.4 Stage 2, Flight 2A Performance Characteristics

Stage 2, Flight 2A is *inertially* pointing with the body x-axis in the plane of the orbit perpendicular to the sun line, and a roll angle attitude about the body x-axis equal to the solar beta angle in order to obtain full power from the body fixed PV array. Flight 2A is launched to an altitude of about 213 n.mi., the exact value depending on the decay rate and atmospheric density conditions for Stage 1. Nominal launch date is April, 1998.

Stage 2 is not intended to provide microgravity science.

Table 5.2.4-1 summarizes the lifetime characteristics of Stage 2 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 36.9 lbs/ft^2. No reboost was performed for this stage as it is required to decay to 204 n.mi. in order to rendezvous with Stage 3. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.2.4-1 Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
213	N/A	N/A	11,600	N/A	223

In a $+2\sigma$ atmospheric density environment, the minimum control yaw attitude varies between ±2 degrees depending on the solar beta angle. The roll attitude is equal to the solar beta angle, and the pitch attitude is such that the PV array is pointing to the sun. This results in a ballistic coefficient which varies from 170 to 190 Kg/m^2 depending on the day of year and orbit ascending node. No microgravity experimentation is planned for Flight 2A.

Table 5.2.4-2 summarizes the control characteristics of Stage 2 in a design atmosphere environment. Since the configuration is held in a nearly inertial attitude, an accumulation of angular momentum will occur, which will require periodic jet desaturation about once a week.

Table 5.2.4-2 Control Characteristics Summary

Solar Beta Angle	Attitude Yaw	Maximum Deviation	Angular Mom Accumulation	Fuel Requirements
0.0 degrees	-1.3 degrees	< ± 0.1 degrees	7 N-m-s/orbit	0.01 Kg/day
75.0 degrees	0.7 degrees	< ± 0.1 degrees	39 N-m-s/orbit	0.23 Kg/day

5.2.5 Issues and Concerns

Solar inertial flight mode:

Currently also an issue in the baseline due to thermal concerns. A less severe thermal environment could be obtained by flying this stage in an LVLH/arrow mode but larger and more complex single axis articulating arrays would be required.

5.3 Stage 3 Flight Characterization

5.3.1 Stage 3 - Flight 3A Shuttle Flight Manifest

The third assembly flight delivers the Z1 truss segment with the Control Moment Gyros (CMGs) and the Ku-band antenna, the Extra Vehicular Activity System (EVAS) and the High Pressure N2 & O2 tanks on a spacelab pallet. Table 5.3.1-1 lists the Shuttle Flight Manifest for Stage 3 - Flight 3A. The total mass of the station hardware to orbit is 14004 lbs (not including high pressure gas carriers). The second section of table 5.3.1-1 shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 26871 lbs to 204 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 10457 lbs. This margin should be sufficient enough to allow for manifesting high pressure gas to be used for repressurization and leakage make up.

5.3.2 Stage 3 Configuration

Figure 5.3.2-1 displays the isometric view of Stage 3 after the Shuttle departs and the scheduled assembly is completed. Figure 5.3.2-2 shows the front, side, top and isometric views of Stage 3 with the Shuttle attached.

5.3.3 Flight 3A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 2 occurs along +R bar at an altitude of 204 n.mi. Station rendezvous attitude is +ZVV and +X Nadir. The shuttle docks with PMA2 on the forward CBM of Node1 with the Shuttle nose in Station nadir direction and into the velocity vector.

The SRMS removes Z1 truss from payload bay and attaches it to the Node 1 zenith CBM (active CBM). The SRMS removes the High Pressure gas tanks from the Spacelab Pallet (SLP) and atta hes the tanks to the port and starboard faces of the aft bus stinger (Note: this will be done for both sets of tanks, requiring two days of operations and installation.)

<u>System Resource/Functionality</u>

Stage 2 functionality, plus:

- CMGs (inactive)
- Ku-band Communications (inactive)
- PMA3 docking capability

U.S. O_2/N_2 Source Available

Resources Available:	*Power:*	*3200 W*	*(Bus-1)*
	Thermal:		
	EVA:	*36 crew-hours*	
Resources Required:	*Power:*	*1229 W*	*(U.S. Housekeeping)*
		1600 W	*(Bus-1 Housekeeping)*
	Thermal:	*TBD*	
	EVA:	*27:50 crew-hours*	

Table 5.3.3-1 Stage 3 - Flight 3A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
Z1 truss	8379	
CMGs	4190	
Ku-band Antenna	550	
Spacelab Pallet - A		1531
EVAS	885	880
High Pressure N2 tank	TBD	
High Pressure O2 tank	TBD	
subtotal	14004	2411

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi.i at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		1600
Variable Integrated Hardware		-1704
APCU-I	714	
Additional Attach Hardware	990	
	1704	
Variable Shuttle Consumables		-3496
Food and Gear (-55lbs/day over 6)	165	
5th & 6th N2 tank	256	
5th Cryo tank & Fluid	1575	
OMS	1500	
	3496	
Middeck Lockers		-390
Generic Integrated Hardware		-5474
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER (2)	200	
Misc integration hardware	118	
Attach Hardware	990	
	5474	
Weight Growth Reserve		-1350
Total Shuttle Lift Capability		26871

Mission Flight Margin		10457

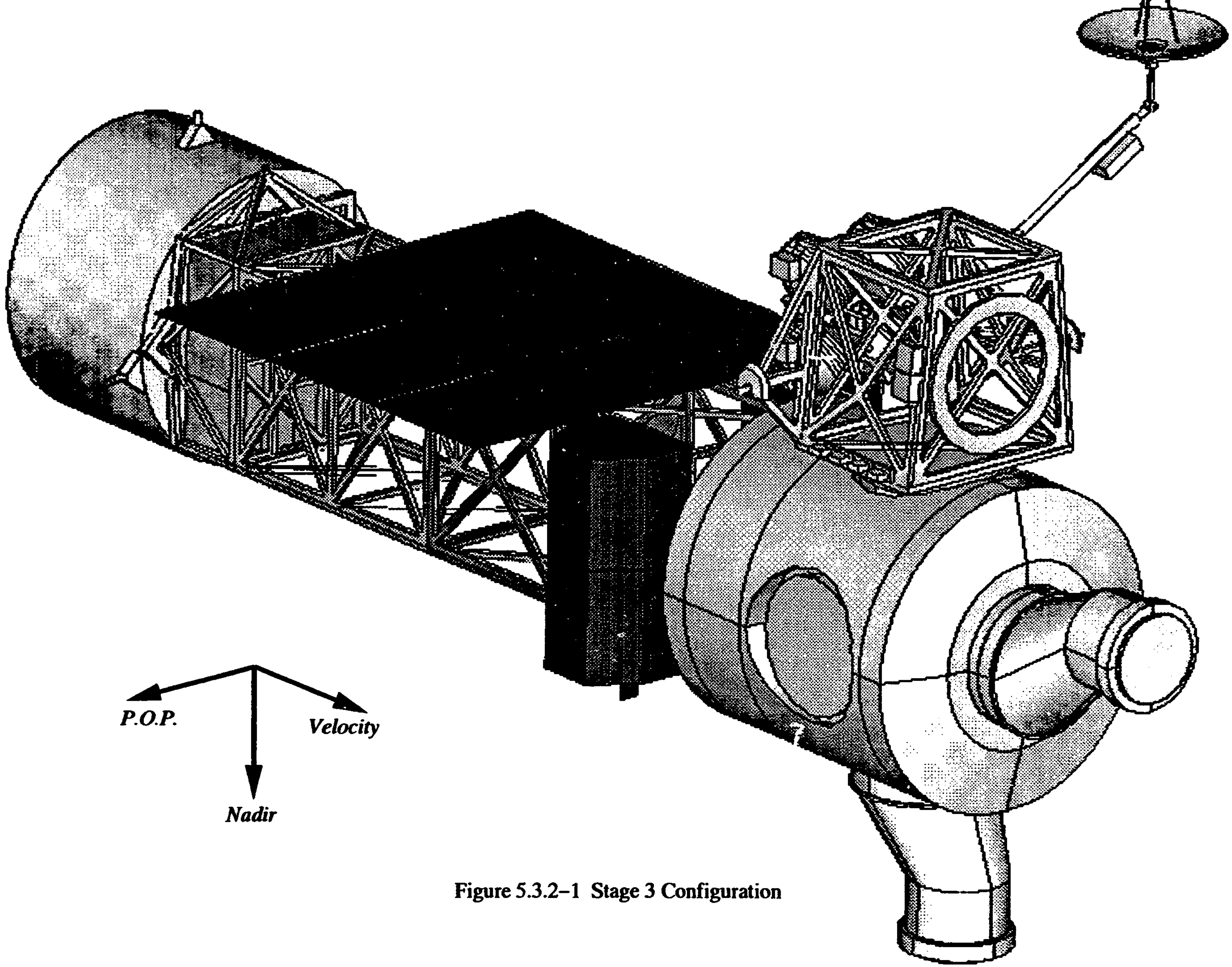


Figure 5.3.2-1 Stage 3 Configuration

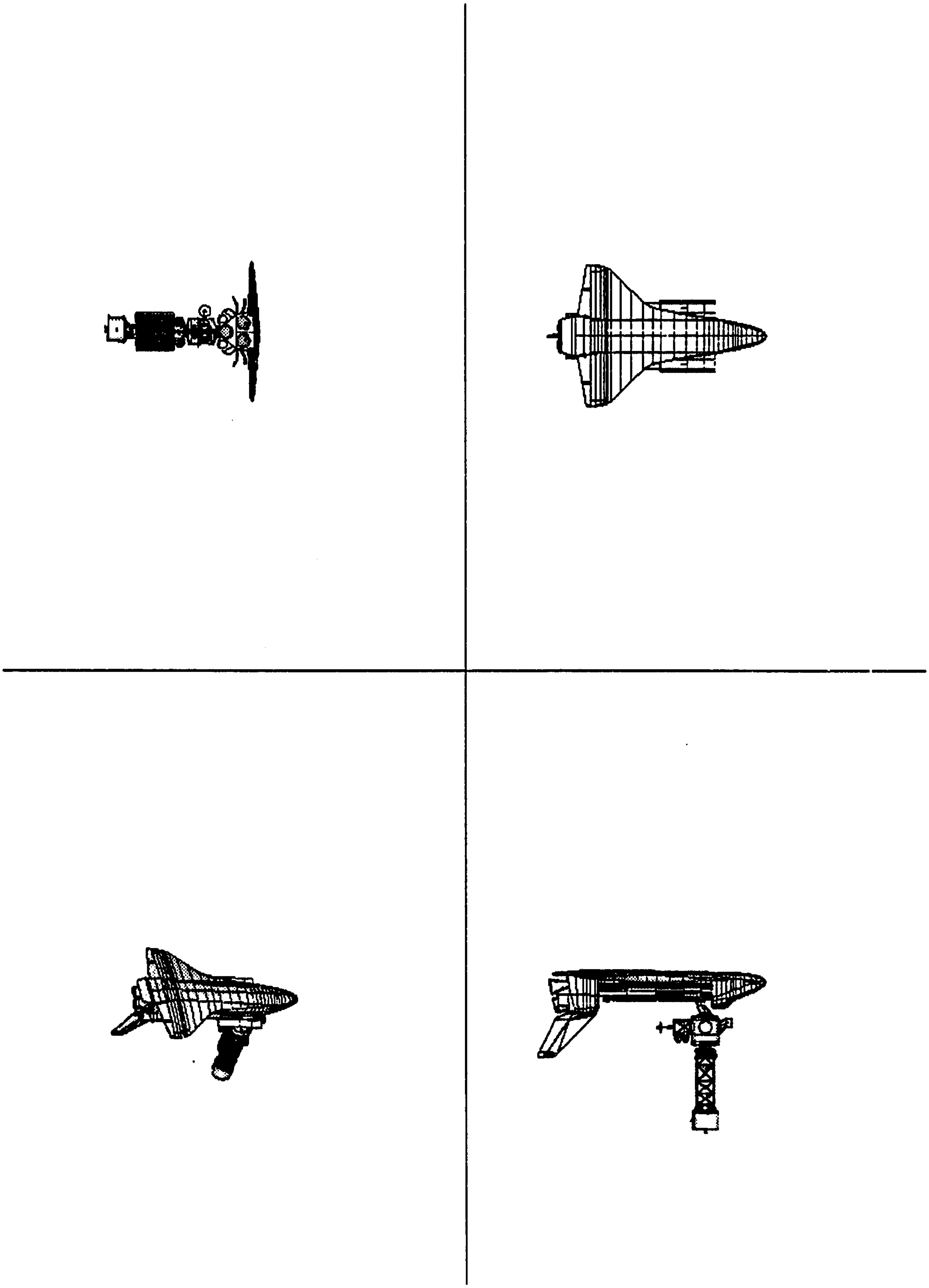


Figure 5.3.2-2 Stage 3 Configuration with Shuttle

5.3.4 Stage 3, Flight 3A Performance Characteristics

Stage 3, Flight 3A is *inertially* oriented with the body x-axis in the plane of the orbit perpendicular to the sun line, and a roll angle attitude about the body x-axis equal to the solar beta angle in order to obtain full power from the body fixed PV array. Flight 3 is launched to an altitude of about 204 n.mi., the exact value depending on the decay rate and atmospheric density conditions for Stage 2. Nominal launch date is June, 1998.

Stage 3 is not intended to provide microgravity science.

Table 5.3.4-1 summarizes the lifetime characteristics of Stage 3 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 42.8 lbs/ft^2. No reboost was performed for this stage as it is required to decay to 190 nmi. in order to rendezvous with Stage 4. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.3.4-1 Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
204	N/A	N/A	11,600	N/A	160

In a $+2\sigma$ atmospheric density environment, the minimum control yaw attitude varies between ±4 degrees depending on the solar beta angle. The roll attitude is equal to the solar beta angle, and the pitch attitude is such that the PV array is pointing to the sun. This results in a ballistic coefficient which varies from 200 to 218 Kg/m^2 depending on the day of year and orbit ascending node. No microgravity experimentation is planned for Stage 3A.

Table 5.3.4-2 summarizes the control characteristics of Stage 3 in a design atmosphere environment. Since the configuration is held in a nearly inertial attitude, an accumulation of angular momentum will occur, which will require periodic jet desaturation approximately once a day.

Table 5.3.4-2 Control Characteristics Summary

Solar Beta Angle	Attitude Yaw	Maximum Deviation	Angular Mom Accumulation	Fuel Requirements
0.0 degrees	-1.5 degrees	< ± 0.1 degrees	33 N-m-s/orbit	0.06 Kg/day
75.0 degrees	-3.8 degrees	< ± 0.1 degrees	220 N-m-s/orbit	1.23 Kg/day

5.3.5 Issues and Concerns

Solar inertial flight mode as in Stage 2.

Development of high pressure gas carriers and associated interfaces.

5.4 Stage 4 Flight Characterization

5.4.1 Stage 4 - Flight 4A Shuttle Flight Manifest

The Shuttle delivers the P6 segment. Table 5.4.1-1 lists the Shuttle Flight Manifest for Stage 4 - Flight 4A. The total mass of the station hardware to orbit is 32956 lbs. The second section of table 5.4.1-1 shows the Shuttle Performance and hardware/ consumables required for the mission resulting in the net Shuttle Lift Capability of 34075 lbs to 190 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a mission flight margin of 1119 lbs.

5.4.2 Stage 4 Configuration

Figure 5.4.2-1 displays the isometric view of Stage 4 after the Shuttle departs and the scheduled assembly is completed. Figure 5.4.2-2 shows the front, side, top and isometric views of Stage 4 with the Shuttle attached.

5.4.3 Flight 4A Assembly Operations Description

Rendezvous of the Shuttle with Stage 3 occurs along +R bar at an altitude of 190 n.mi. Station rendezvous attitude is -XVV and +Z Nadir. The Shuttle docks to PMA3 on the nadir CBM of Node1 with the Shuttle nose in the -X direction (+V bar).

Flight 4A is scheduled to be an 8 day mission with 2 EVAs. Prior to installing the P6 ITS on Z1, the S-band antenna is attached to the P6 IEA (Note: the S-band RF group is relocated to P1 ITS on Flight 1 J/A). The SRMS grapples an FRGF on the P6 truss, removes the segment from the Shuttle payload bay, and installs it on the zenith face of the Z1 truss. The P6 radiator and PV arrays are deployed and activated utilizing both EVA and IVA operations. The temporary EEATCS radiators are not deployed.

At the conclusion of this flight, the equipment located on the Z1 truss segment is receiving power from the P6 power module. Following separation, Stage 4 flight mode is LVLH with the Bus-1/Node section aligned along the velocity vector.

System Resource/Functionality

Stage 3 functionality, plus:

- Active P6 PV module (In temporary location on Z1 Zenith)
- Active S-band (low data rate)
- 2 P6 EEATCS PFCS checked out
- 2 Temporary Thermal Radiators on P6 (Not deployed and activated until flight 5A)

Resources Available:	*Power:*	*1200 W*	*(Bus-1)*
		3600 W	*(P6 Power Module)**
	Thermal:	*TBD*	
	EVA:	*24 crew-hours*	
Resources Required:	*Power:*	*888 W*	*(U.S. Housekeeping)*
		1600 W	*(Bus-1 Housekeeping)*
	Thermal:	*TBD*	
	EVA:	*20:20 crew-hours*	

* *Assumes worst case solar geometry (i.e., 75 deg. beta angle)*

Table 5.4.3-1 Stage 4 - Flight 4A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
P6 structure	9702	
BG DEPLOYED	1338	
IEA RADIATOR DEPLOY	1486	
P6 PV SPACER	6615	
IEA BATTERIES (4 Battery sets)	4968	
POA PV Array	2646	
POF PV Array	2646	
S4 IEA Radiator Assembly	1824	
S6 IEA Radiator Assembly	1474	
S-band	256	
subtotal	**32956**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per Nm)		3000
Additional Shuttle Performance Enhancements		1300
Variable Integrated Hardware		-893
APCU-I	714	
Misc. hardware	179	
	893	
Variable Shuttle Consumables		-238
Food & Gear (-55 lbs/day over 6)	110	
5th N2 tank	128	
	238	
Middeck Lockers		-305
Generic Integrated Hardware		-5474
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER (2)	200	
Misc integration hardware	118	
Attach Hardware	990	
	5474	
Weight Growth Reserve		-1000
Total Shuttle Lift Capability		**34075**
Mission Flight Margin		**1119**

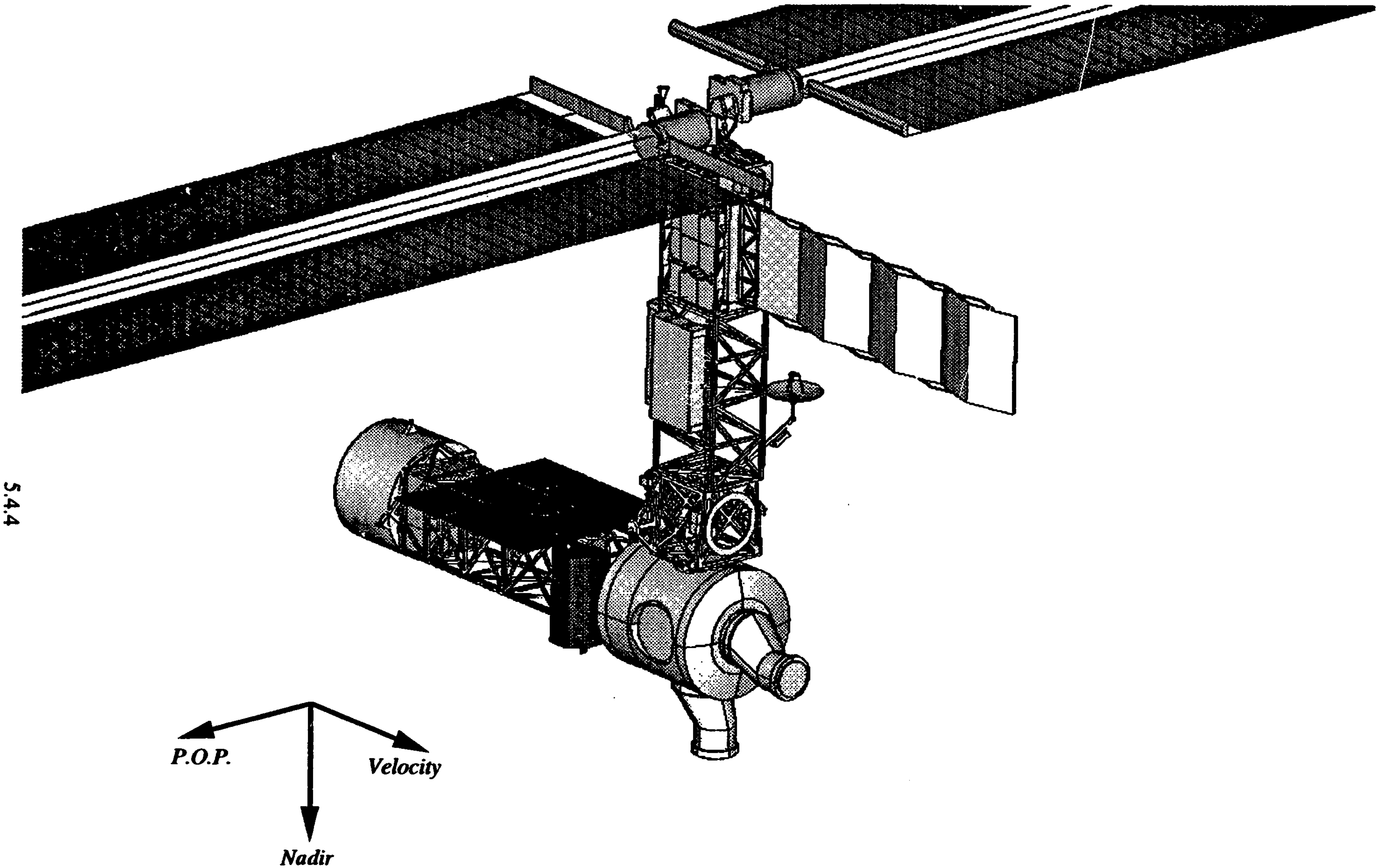


Figure 5.4.2-1 Stage 4 Configuration

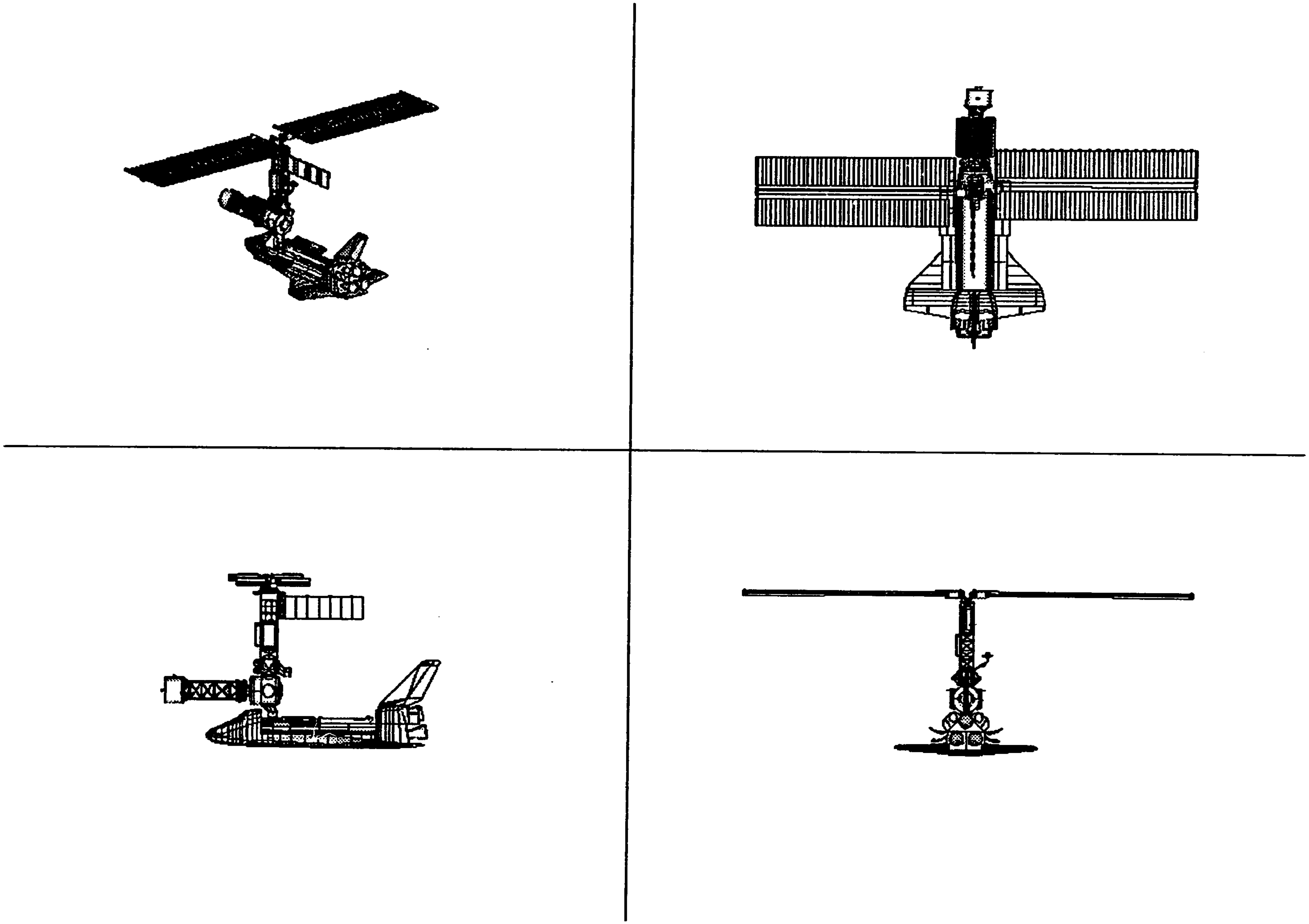


Figure 5.4.2–2 Stage 4 Configuration with Shuttle

5.4.4 Stage 4, Flight 4A Performance Characteristics

Stage 4, Flight 4A is assembled at a 190 nautical mile altitude in an LVLH flight mode with the bus-to-node section aligned along the velocity vector, and 2 *feathered* PV arrays perpendicular to the orbit plane. The nominal launch date is September, 1998.

Stage 4 is not intended to provide microgravity science.

Table 5.4.4-2 summarizes the reboost lifetime characteristics of Stage 4 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 37.9 lbs/ft^2. The reboost was performed using the aft bus, which currently has a reboost efficiency of 86.7%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement. This stage violates the 90 day decay to 150 n.mi. lifetime requirement.

Table 5.4.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
190	216	1,338	10,262	N/A	80

The control characteristics of Stage 4 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.4.4-1. The CMGs were augmented with a 5000 N-m-s momentum wheel. Table 5.4.4-2 summarizes the control characteristics depicted in the plots.

Table 5.4.4-2 Control Characteristics Summary

Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
-2.0 degrees	-44.4 degrees	2.1 degrees	± 2.3 degrees	225 N-m-s

5.4.5 Issues and Concerns

This stage violates the 90 day to 150 n.mi. altitude lifetime requirement. An increase in rendezvous altitude could alleviate the problem but additional Shuttle lift capability would be required.

This stage has a pitch flight attitude that exceeds ±15 degrees (without an attached Shuttle). The large pitch attitude results from a combination of inertia properties that are nearly identical in all axes and large pitch aerodynamic torques resulting from the P6 solar power unit. Significant configuration changes would be required to eliminate this problem.

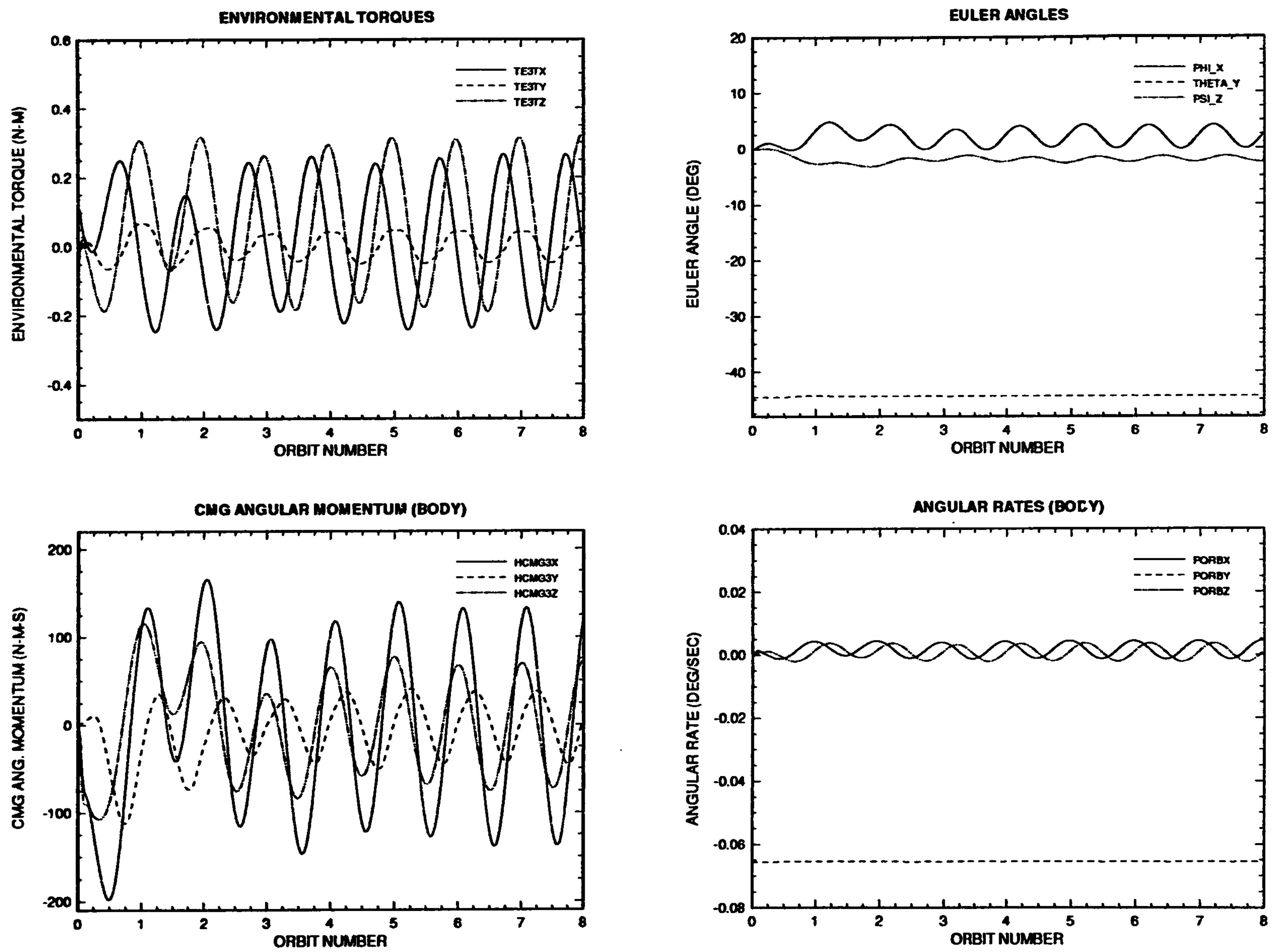


Figure 5.4.4-1 Stage 4 control plots without Shuttle attached.

5.5 Stage 5 Flight Characterization

5.5.1 Stage 5 - Flight 5A Shuttle Flight Manifest

The Shuttle delivers the U.S. Lab. Table 5.5.1-1 lists the Shuttle Flight Manifest for Stage 5 - Flight 5A. The total mass of the station hardware to orbit is 29765 lbs. The second section of table 5.5.1-1 shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 30218 lbs to 205 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 453 lbs.

5.5.2 Stage 5 Configuration

Figure 5.5.2-1 displays the isometric view of Stage 5 after the Shuttle departs and the scheduled assembly is completed. Figure 5.5.2-2 shows the front, side, top and isometric views of Stage 5 with the Shuttle attached.

5.5.3 Flight 5A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 4 occurs along +R bar at an altitude of 205 n.mi. Station rendezvous attitude is -XVV and +Z Nadir. The Shuttle docks to PMA3 on the nadir CBM of Node 1 with the Shuttle nose in the -X direction.

Assembly Flight 5A is a nine day mission with 3 EVAs. Following the disconnection of the PMA2-to-Node1 umbilicals, the SRMS relocates PMA2 from Node1 forward to the Z1 truss CBM. The SRMS then removes the US Lab from the Shuttle payload bay and, after flipping the Lab end over end, berths the element to the Node 1 forward CBM. The EEATCS radiators located on ITS P6 are deployed and, along with the CMGs, activated. PMA2 is disconnected from the Z1 CBM and relocated to the Lab forward port.

Following separation, Stage 5 flight mode is LVLH with the Bus-1/Node section aligned along the velocity vector.

System Resource/Functionality

Stage 4 functionality, plus:

- Lab Core Systems Active in the following racks:
  - U.S. Lab Cabin Air / Moderate Temperature Thermal Control System rack
  - U.S. Lab Cabin Air / Low Temperature TCS rack
  - U.S. Lab Avionics #1 rack
  - U. S. Lab Avionics #2 / Condensate Water Storage rack
- PMA2 relocated to Lab forward CBM (provides docking ability on following flight)
- Active P6 mounted EATCS
- Station CMGs providing attitude control

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*36 crew-hours*	
Resources Required:	*Power:*	*5,716 W*	*(U.S. Housekeeping, including 400 W to Bus from station on this and all subsequent flights)*
		TBD W	*(Payload)*
	Thermal:	*TBD W*	
	EVA:	*31:00 crew-hours*	

Table 5.5.3-1 Stage 5, Flight 5A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
Lab	25860	
LAF3 - Avionics Rack	998	
LAC6 - Avionics/CWS Rack	1056	
LAP6 - CA/LT TCS Rack	921	
LAS6 - CA/MT TCS Rack	930	
subtotal	**29765**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		1500
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-714
APCU-I	714	
	714	
Variable Shuttle Consumables		-549
Food & Gear (-55 lbs/day over 6)	165	
5th, 6th & 7th N2 tanks	384	
	549	
Middeck Lockers		-300
Generic Integrated Hardware		-5474
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER (2)	200	
Misc integration hardware	118	
Attach Hardware	990	
	5474	
Weight Growth Reserve		-1930
Total Shuttle Lift Capability		**30218**

Mission Flight Margin		**453**

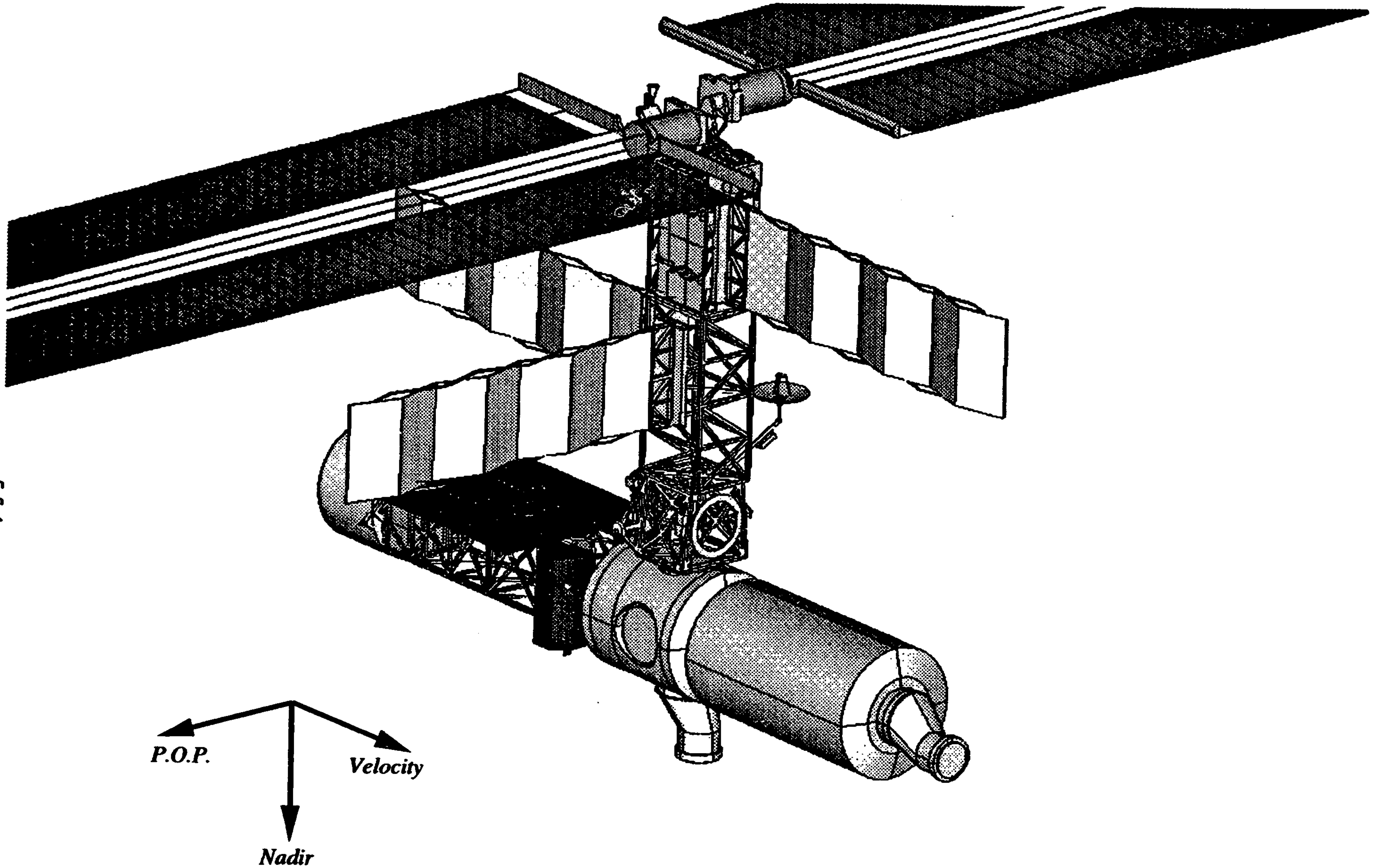


Figure 5.5.2–1 Stage 5 Configuration

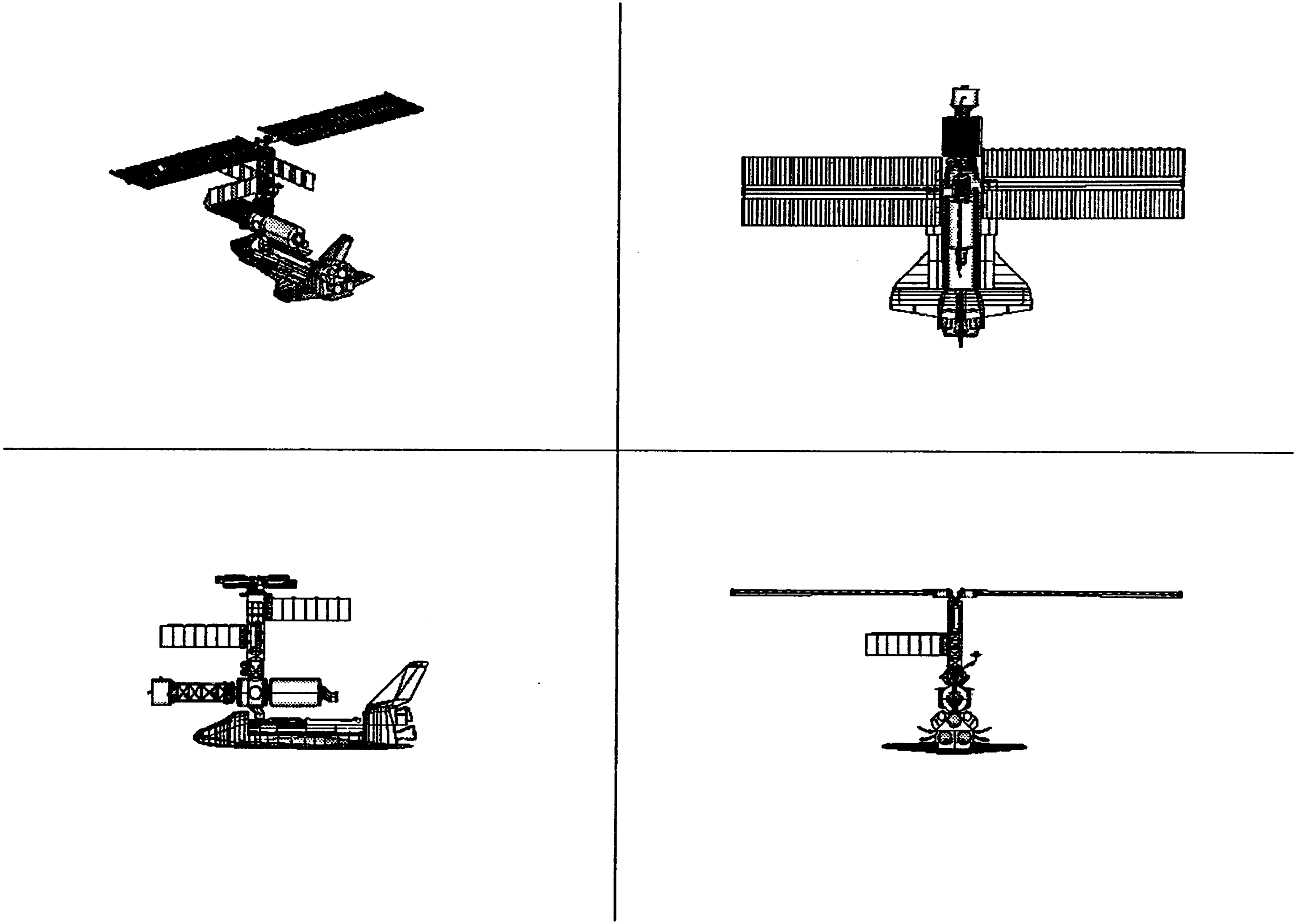


Figure 5.5.2-2 Stage 5 Configuration with Shuttle

5.5.4 Stage 5, Flight 5A Performance Characteristics

Stage 5, Flight 5A is assembled at a 205 n.mi. altitude in an LVLH flight mode with the bus-to-node section aligned along the velocity vector, and 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is November, 1998.

Stage 5 is not intended to provide microgravity science.

Table 5.5.4-1 summarizes the reboost lifetime characteristics of Stage 5 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 10.0 lbs/ft^2. The reboost was performed using the aft bus, which has a reboost efficiency of 96.5%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement. This stage violates the 90 day decay to 150 n.mi. lifetime requirement.

Table 5.5.4-1 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
205	230	1,509	8,753	N/A	38

The control characteristics of Stage 5 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.5.4-1. The CMGs were augmented with a 5000 N-m-s momentum wheel. Table 5.5.4-2 summarizes the control characteristics depicted in the plots.

Table 5.5.4-2 Control Characteristics Summary

Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
-0.1 degrees	-54.1 degrees	0.1 degrees	± 3.8 degrees	3600 N-m-s

None of the PDR or CDR CMG control algorithms were able to maintain the attitude of the combined Stage 5/Shuttle configuration while managing the angular momentum build-up. This would suggest that a customized control algorithm might be required.

5.5.5 Issues and Concerns

This stage violates the 90 day to 150 n.mi. altitude lifetime requirement.

This stage has a pitch flight attitude that exceeds ±15 degrees (without an attached Shuttle).

The CMG control simulations for the mated stack all eventually went unstable. The currently existing control laws can probably be tuned to the unique inertia properties of the mated configuration to obtain a stable CMG control simulation.

There is a possibility of some indirect plume impingement of the aft P6 radiator from the aft bus attitude control thrusters. The potential of plume impingement could be lessened by utilizing a longer extender section (see Section 3.3).

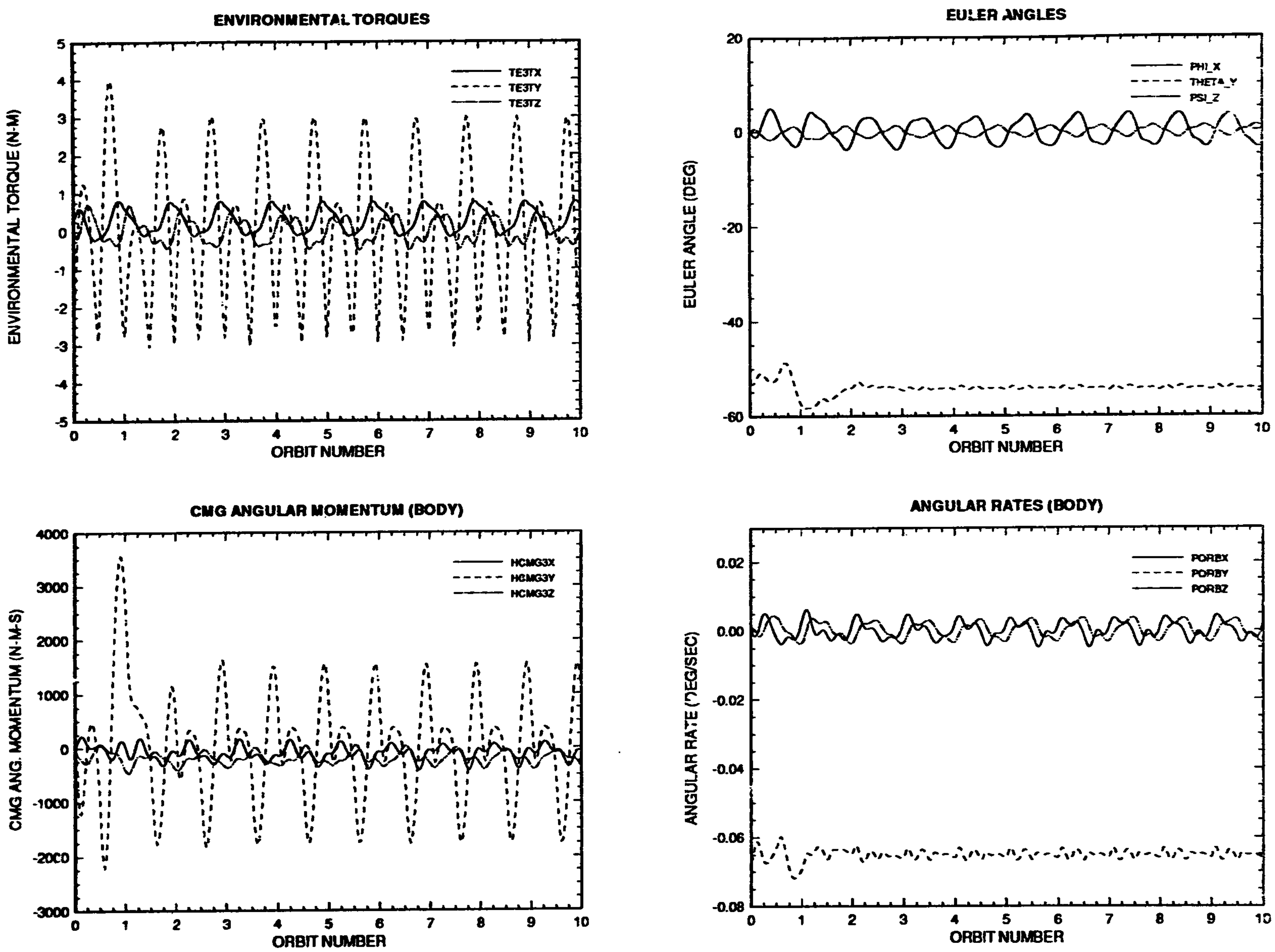


Figure 5.5.4-1 Stage 5 control plots without Shuttle attached.

5.6 Stage 6 Flight Characterization

5.6.1 Stage 6 - Flight 6A Shuttle Flight Manifest

The STS delivers a MPLM with US Lab system racks. Table 5.6.1-1 lists the Shuttle Flight Manifest for Stage 6 - Flight 6A. The total mass of the station hardware to orbit is 12852 lbs and FSE mass of 13126 lbs. The second section of table 5.6.1-1 shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 26635 lbs to 215 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 657 lbs.

5.6.2 Stage 6 Configuration

Figure 5.6.2-1 displays the isometric view of Stage 6 after the Shuttle departs and the scheduled assembly is completed. Figure 5.6.2-2 shows the front, side, top and isometric views of Stage 6 with the Shuttle attached.

5.6.3 Flight 6A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 5 occurs along +V bar at an altitude of 215 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the forward Lab CBM in a tail down orientation.

Flight 6A is a 12 day mission with 3 EVAs. Installation of the Lab Cradle Assembly (LCA) on the Lab occurs during the first EVA. The SRMS relocates PMA3 from the Node 1 nadir port to the Node 1 port CBM. The SRMS removes the SSRMS/SLP from payload bay and installs it on the LCA. During EVA operations, the UHF antenna is installed on Lab nadir, and the SSRMS to Lab umbilicals are installed. The SSRMS is deployed, checked-out and powered to a keep-alive state. The SRMS unberths the MPLM from the Shuttle payload bay and attaches it to the Node 1 nadir port. Following mating of the MPLM-to-Node 1 utility lines, the MPLM is activated. Following transfer of the MPLM contents to the Lab, the MPLM and SLP are returned to the shuttle payload bay.

Following separation, Stage 6 flight mode is LVLH with the Bus-1/Node section aligned along the velocity vector.

System Resource/Functionality

Stage 5 functionality, plus:

- Additional Lab racks delivered (7 racks)
    - U.S. Lab Avionics 3 Rack
    - U.S. Lab Fluid System Service/Stowage Rack
    - U.S. Lab Air Revitalization System Rack
    - U.S. Lab DDCU/Avionics Rack
    - MSS/Av/Lab MSS Console/Storage Rack
    - MSS/Av/Cupola MSS Console/Storage Rack
    - Temporary CHeCS Rack
- One additional Stowage Rack delivered
- UHF antennas on Lab are functional
- SSRMS is operational
- External Node 1 camera is functional
- RF link
- Ku-band system is checked out after shuttle departure
- Payload racks activated and checked out after shuttle departure

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*14 kW*	
	EVA:	*36 crew-hours*	
Resources Required:	*Power:*	*7,334 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		409 W	*(CSA)*
	Thermal:	*TBD W*	
	EVA:	*23:20 crew-hours*	

Table 5.6.3-1 Stage 6 - Flight 6A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
MPLM - 1		10626
LAF2 - Avionics 3 Rack	1349	
LAF5 - FSS/Sowage Rack	863	
LAF6 - ARS Rack	1196	
LAF1 - DDCU/Avionics Rack	807	
LAP5 - MSS/LAB Console/Storage	1310	
LAS5 - MSS/Cupola Console/Storage	1212	
TLAF4 - Temp CHeCS	986	
APM/US Storage Rack 1	930	
Spacelab Pallet 2		1850
Module to Truss Common Attach Structure	800	
UHF Antenna	91	
SSRMS	3308	650
subtotal	**12852**	**13126**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		500
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-1704
APCU-I	714	
Additional Attach Hardware	990	
	1704	
Variable Shuttle Consumables		-2417
Food & Gear (-55 lbs/day over 6)	330	
5th, 6th, 7th & 8th N2 tanks (@128 lbs/N2)	512	
5th Cryo Tank & Fluid	1575	
	2417	
Middeck Lockers		-305
Generic Integrated Hardware		-5474
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER (2)	200	
Misc integration hardware	118	
Attach Hardware	990	
	5474	
Weight Growth Reserve		-1650
Total Shuttle Lift Capability		**26635**

Mission Flight Margin		**657**

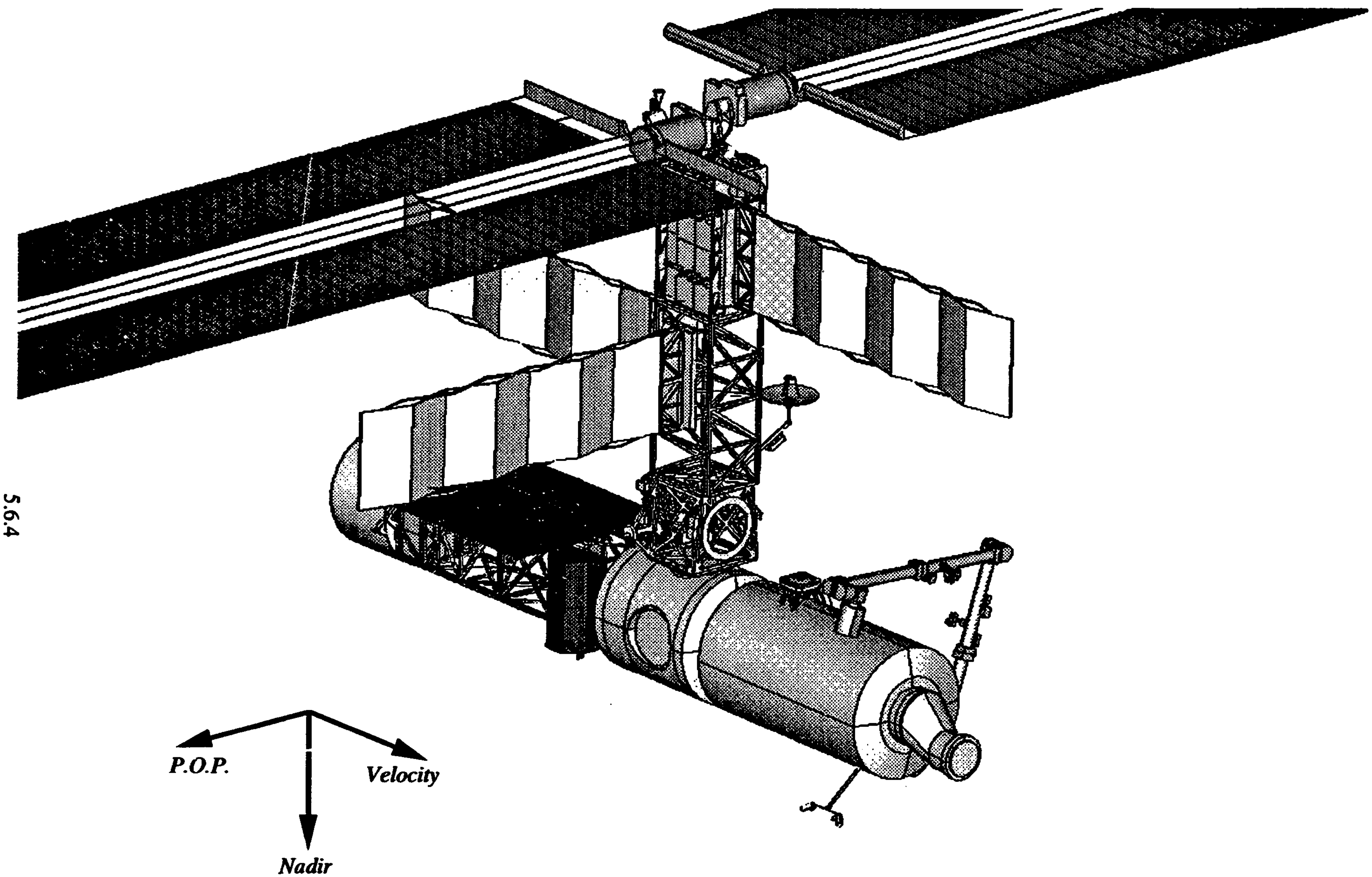


Figure 5.6.2-1 Stage 6 Configuration

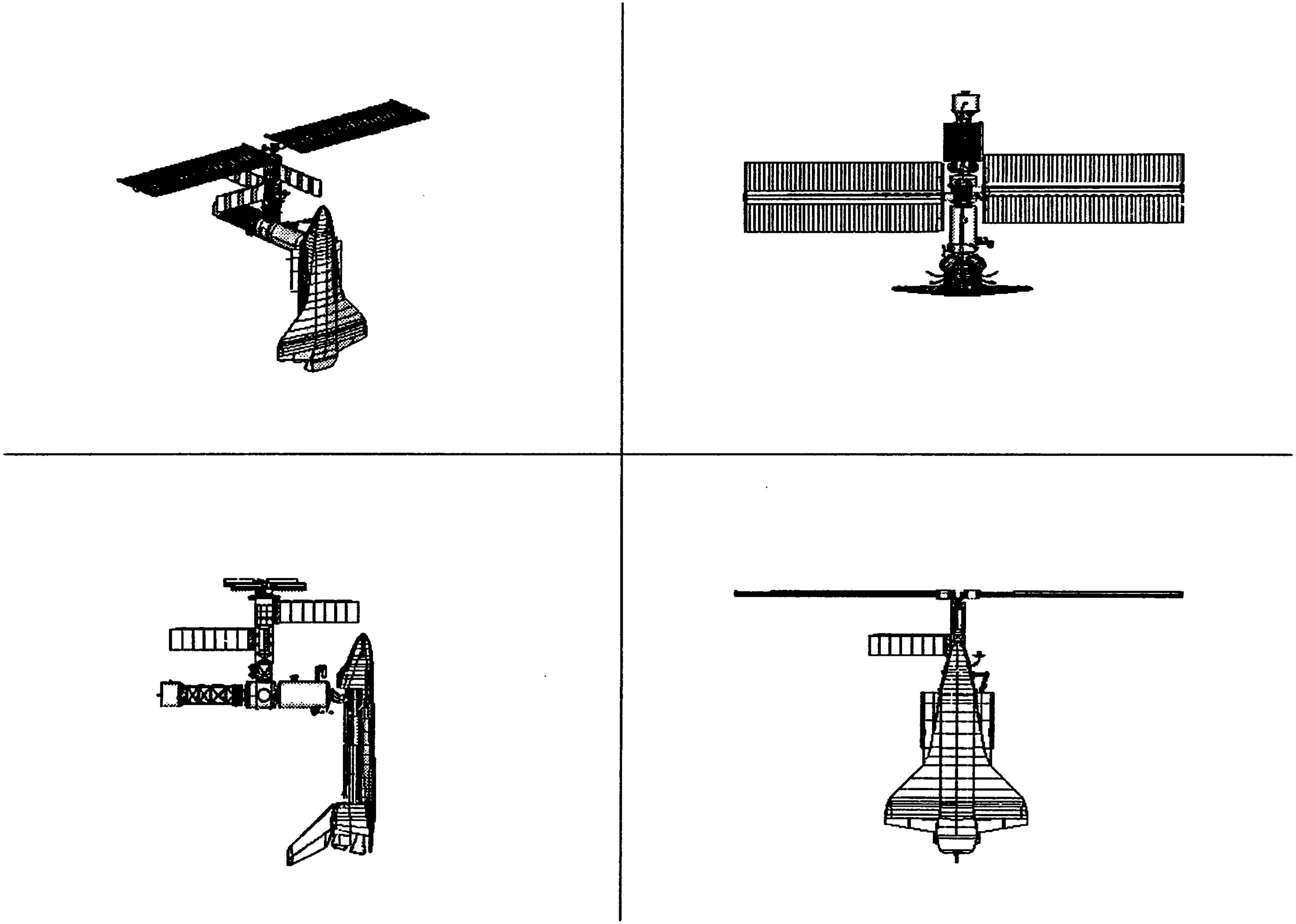


Figure 5.6.2-2 Stage 6 Configuration with Shuttle

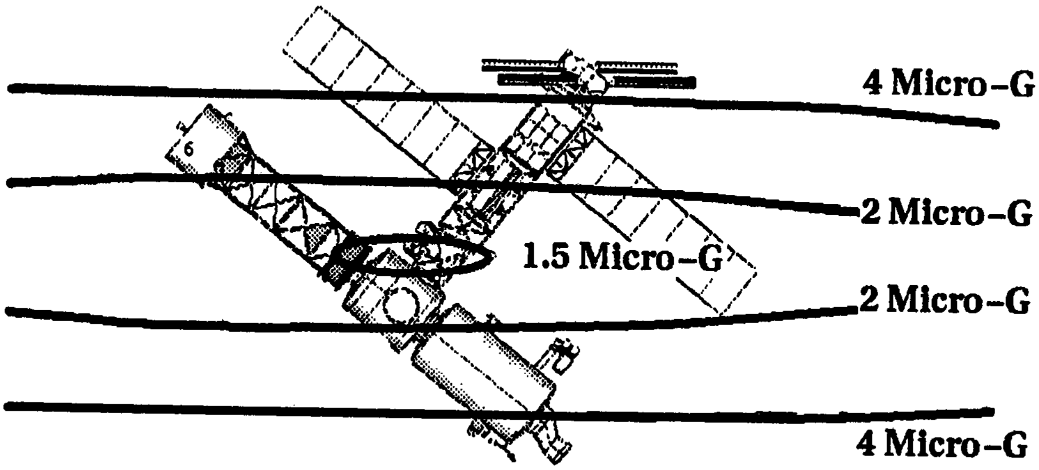
5.6.4 Stage 6, Flight 6A Performance Characteristics

Stage 6, Flight 6A is assembled at a 215 n.mi. altitude in an LVLH flight mode with 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is December, 1998.

Stage 6 is the first flight intended to provide the science users with a microgravity environment. In a +2σ atmosphere (solar flux = 233.7, geomagnetic index = 20.1) this stage has a flight attitude of yaw = 0, pitch = -38.4, and roll = 0. These characteristics result in a microgravity environment as depicted in figure 5.6.4-1. Table 5.6.4-1 list the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. For this configuration there are no ISPR racks in the 1 μg environment.

Table 5.6.4-1 Stage 6 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	3.5
LAS-2	ISPR	3.2
LAS-3	ISPR	2.9
LAS-4	ISPR	2.7
LAS-5	SYS	2.4
LAS-6	SYS	2.1
LAF-1	SYS	4.0
LAF-2	SYS	3.7
LAF-3	SYS	3.4
LAF-4	SYS	3.1
LAF-5	SYS	2.8
LAF-6	SYS	2.6
LAP-1	ISPR	3.5
LAP-2	ISPR	3.2
LAP-3	ISPR	2.9
LAP-4	ISPR	2.7
LAP-5	SYS	2.4
LAP-6	SYS	2.1
LAC-1	ISPR	3.0
LAC-2	ISPR	2.7
LAC-3	ISPR	2.5
LAC-4	ISPR	2.2
LAC-5	ISPR	1.9
LAC-6	SYS	1.7



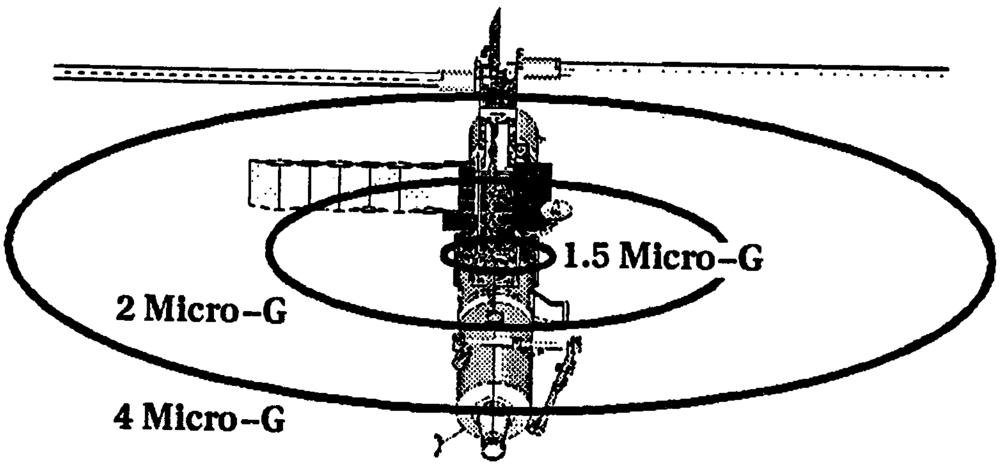


Figure 5.6.4-1 Stage 6 steady-state microgravity environment contours.

Table 5.6.4-2 summarizes the reboost lifetime characteristics of Stage 6 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 10.8 lbs/ft^2. The reboost was performed using the aft bus, which has a reboost efficiency of 98.5%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement. This stage violates the 90 day decay to 150 n.mi. lifetime requirement.

Table 5.6.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
215	236	1,361	7,393	N/A	59

The control characteristics of Stage 6 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.6.4-2. The CMGs were augmented with a 5000 N-m-s momentum wheel. Table 5.6.4-3 summarizes the control characteristics depicted in the plots.

Table 5.6.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	0.0 degrees	-44.5 degrees	0.0 degrees	± 3.5 degrees	2600 N-m-s
w/STS	1.0 degrees	-31.8 degrees	0.1 degrees	± 0.4 degrees	5500 N-m-s

The control characteristics of Stage 6 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.6.4-3. No momentum wheels were required. Table 5.6.4-3 summarizes the control characteristics depicted in the plots.

5.6.5 Issues and Concerns

This stage violates the 90 day to 150 n.mi. altitude lifetime requirement.

This stage has a pitch flight attitude that exceeds ±15 degrees (with and without an attached Shuttle).

There is a possibility of some indirect plume impingement of the aft P6 radiator from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment. The combination of flight attitude, center of mass and low ballistic coefficient yields greater than one micro-G of sensed acceleration in most of the US lab racks.

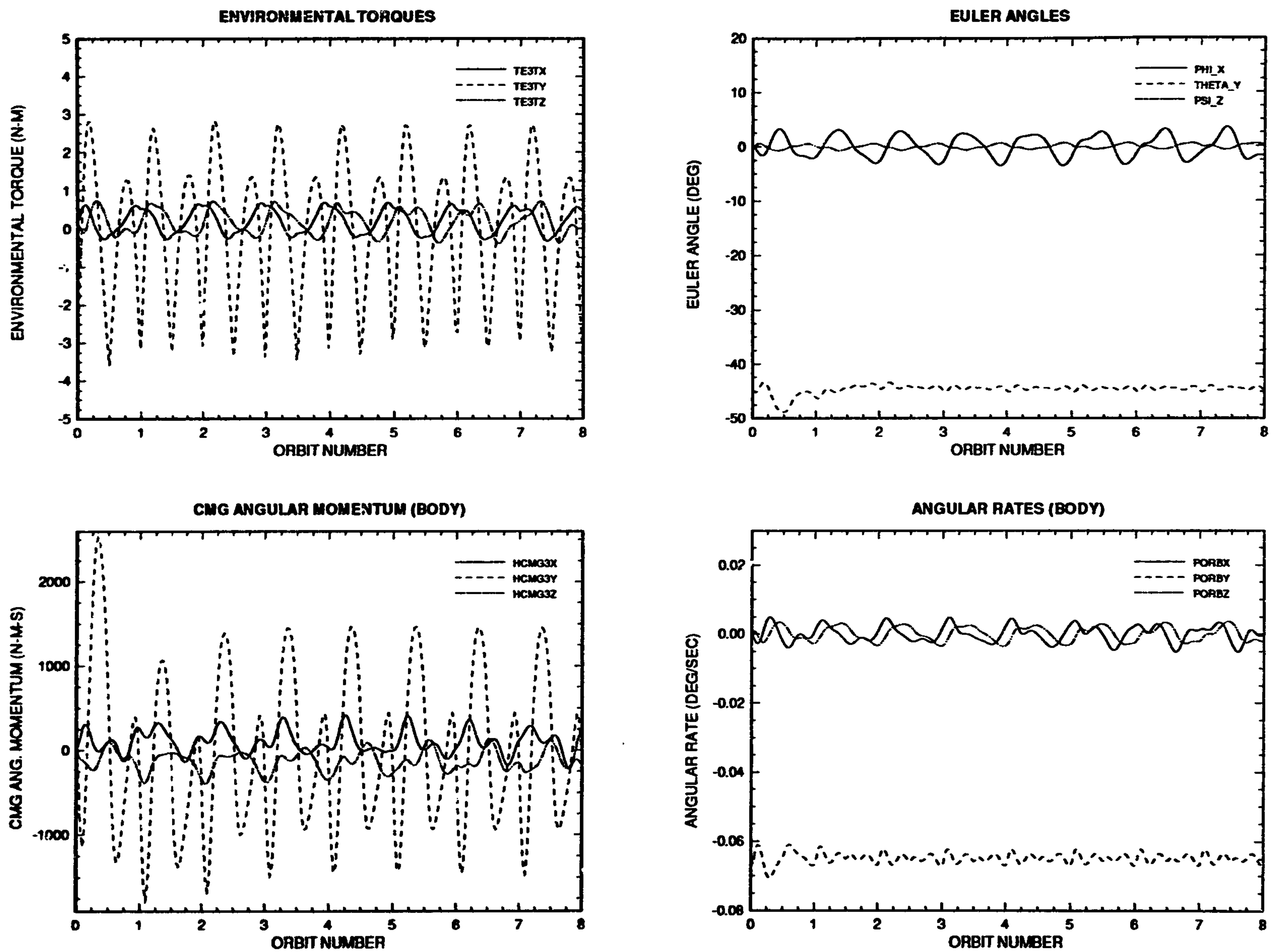


Figure 5.6.4-2 Stage 6 control plots without Shuttle attached.

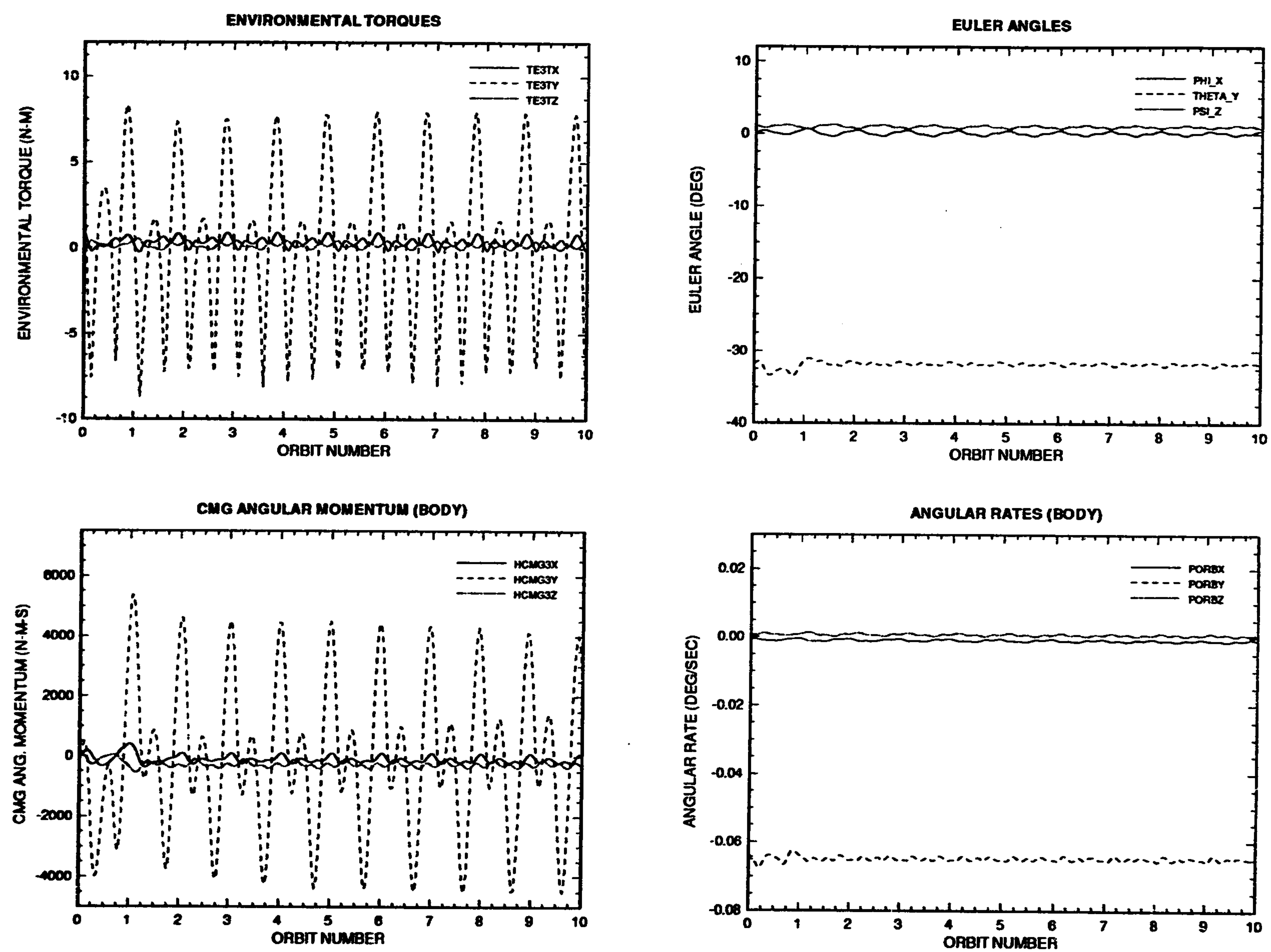


Figure 5.6.4-3 Stage 6 control plots with Shuttle attached.

5.7 Stage 7 Flight Characterization

5.7.1 Stage 7 - Flight UF-1 Shuttle Flight Manifest

The first Utilization flight launches the Mini Pressurized Logistics Module (MPLM) outfitted with 13 International Standard Payload Racks (ISPRs). Table 5.7.1-1 lists the Shuttle Flight Manifest for Stage 7 - Flight UF-1. The total mass of the station hardware to orbit is 15122 lbs and FSE mass of 10705 lbs. The second section of table 5.7.1-1 shows the Orbiter Performance and hardware/consumables required for the mission resulting in the net Orbiter Lift Capability of 26964 lbs to 215 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 1259 lbs.

5.7.2 Stage 7 Configuration

Figure 5.7.2-1 displays the isometric view of Stage 7 after the Shuttle departs and the scheduled assembly is completed. Figure 5.7.2-2 shows the front, side, top and isometric views of Stage 7 with the Shuttle attached.

5.7.3 Flight UF-1 Assembly Operations Description

Rendezvous of the Shuttle with the Stage 6 occurs along +V bar at an altitude of 215 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the forward Lab CBM in a tail down orientation.

Flight UF-1 is a 12 day mission with 0 EVAs. The SRMS removes the MPLM from the Shuttle payload bay and attaches it to the Node 1 nadir port. The Lab is outfitted with 7 science payload racks carried onboard the MPLM. Thirteen ISPRs are offloaded to complete US Lab outfitting. The US Stowage Rack 3 returns in the MPLM for reflight on UF-2. Upon transfer of the equipment out of and into the MPLM, the SRMS reinstalls the MPLM into the shuttle payload bay.

Following separation, Stage 7 flight mode is LVLH with the Bus-1/Node section aligned along the velocity vector.

System Resource/Functionality

Stage 6 functionality, plus:

- Lab ISPR outfitting complete
- TBD days of payload utilization

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*0 crew-hours*	
Resources Required:	*Power*	*7,334 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		409 W	*(CSA)*
	Thermal:	*TBD W*	
	EVA:	*0 crew-hours*	

Table 5.7.3-1 Stage 7 - Flight UF1 Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
MPLM - 2		10705
ISPRs (13) - USL outfitting	15000	
subtotal	**15000**	**10705**

Orbiter Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-1324
APCU-I	714	
ROFU	450	
Misc. Hardware	160	
	1324	
Variable Shuttle Consumables		-3033
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	330	
5th N2 tanks (@128 lbs/N2)	128	
5th Cryo Tank & Fluid	1575	
	3033	
Middeck Lockers		-160
Generic Integrated Hardware		-5474
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER (2)	200	
Misc integration hardware	118	
Attach Hardware	990	
	5474	
Weight Growth Reserve		-1090
Maintenance Reserve		-640
Total Orbiter Lift Capability		**26964**

Mission Flight Margin		**1259**

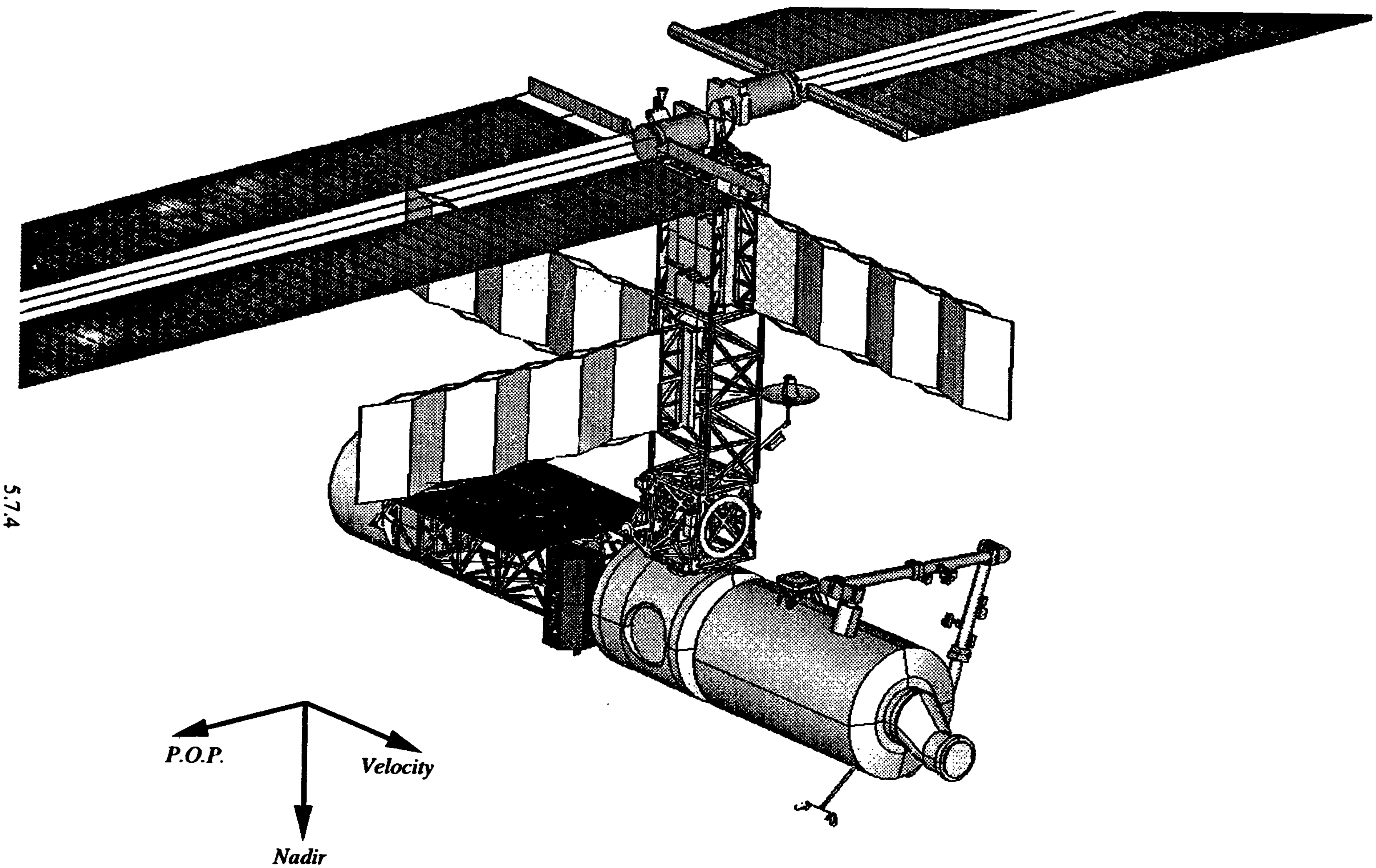


Figure 5.7.2-1 Stage 7 Configuration

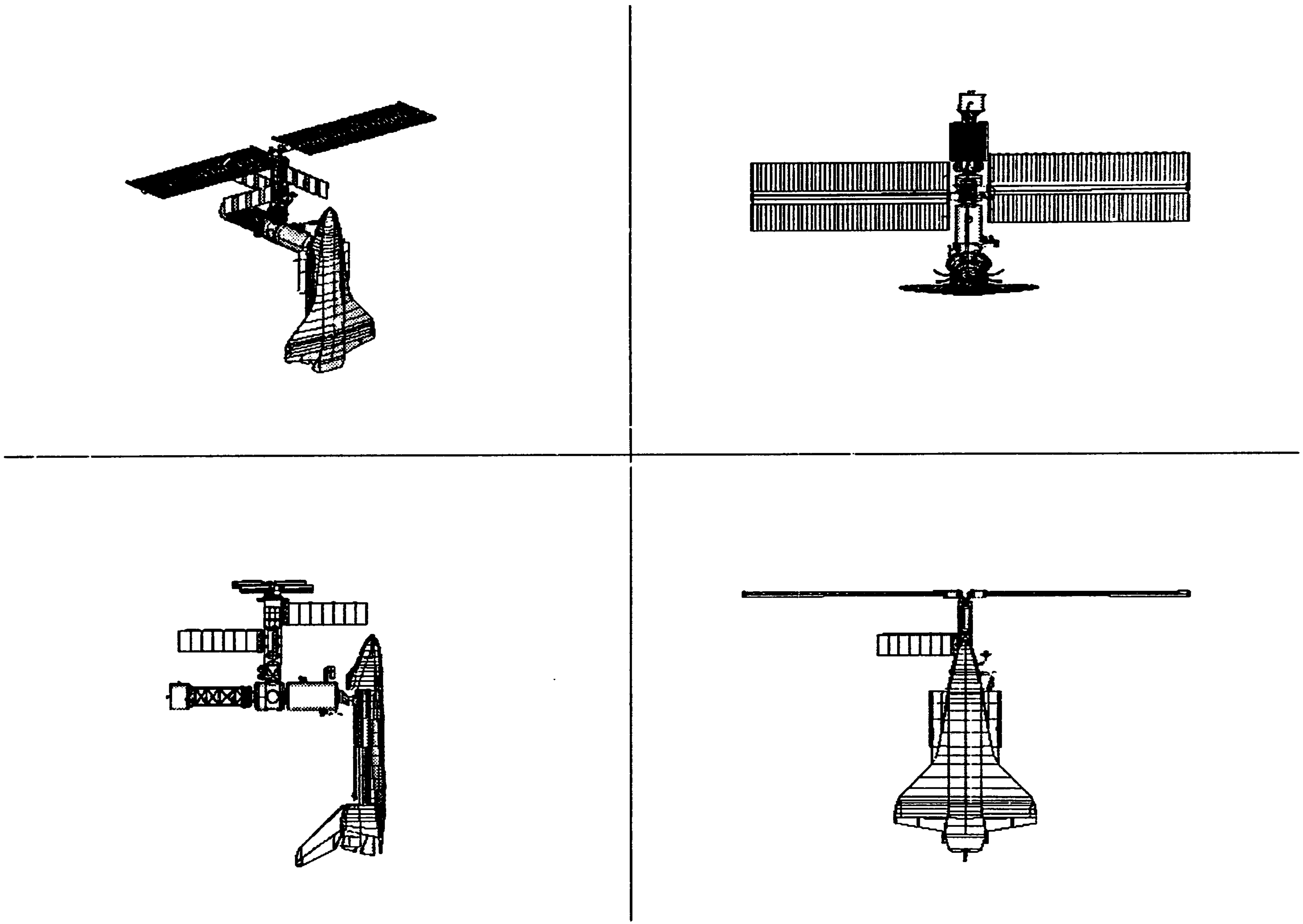


Figure 5.7.2–2 Stage 7 Configuration with Shuttle

5.7.4 Stage 7, Flight UF-1 Performance Characteristics

Stage 7, Flight UF-1 is assembled at a 215 n.mi. altitude in an LVLH flight mode with 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is February, 1999.

The Stage 7 microgravity environment is depicted in figure 5.7.4-1. In a +2σ atmosphere (solar flux = 238.8, geomagnetic index = 19.3) this stage has a flight attitude of yaw = 0, pitch = -30.5, and roll = 0. Table 5.7.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. For this configuration there are no ISPR racks in the 1 μg environment.

Table 5.7.4-1 Stage 7 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	2.9
LAS-2	ISPR	2.7
LAS-3	ISPR	2.4
LAS-4	ISPR	2.2
LAS-5	SYS	2.0
LAS-6	SYS	1.8
LAF-1	SYS	3.4
LAF-2	SYS	3.2
LAF-3	SYS	2.9
LAF-4	SYS	2.7
LAF-5	SYS	2.5
LAF-6	SYS	2.3
LAP-1	ISPR	2.9
LAP-2	ISPR	2.7
LAP-3	ISPR	2.4
LAP-4	ISPR	2.2
LAP-5	SYS	2.0
LAP-6	SYS	1.8
LAC-1	ISPR	2.4
LAC-2	ISPR	2.1
LAC-3	ISPR	1.9
LAC-4	ISPR	1.7
LAC-5	ISPR	1.5
LAC-6	SYS	1.3

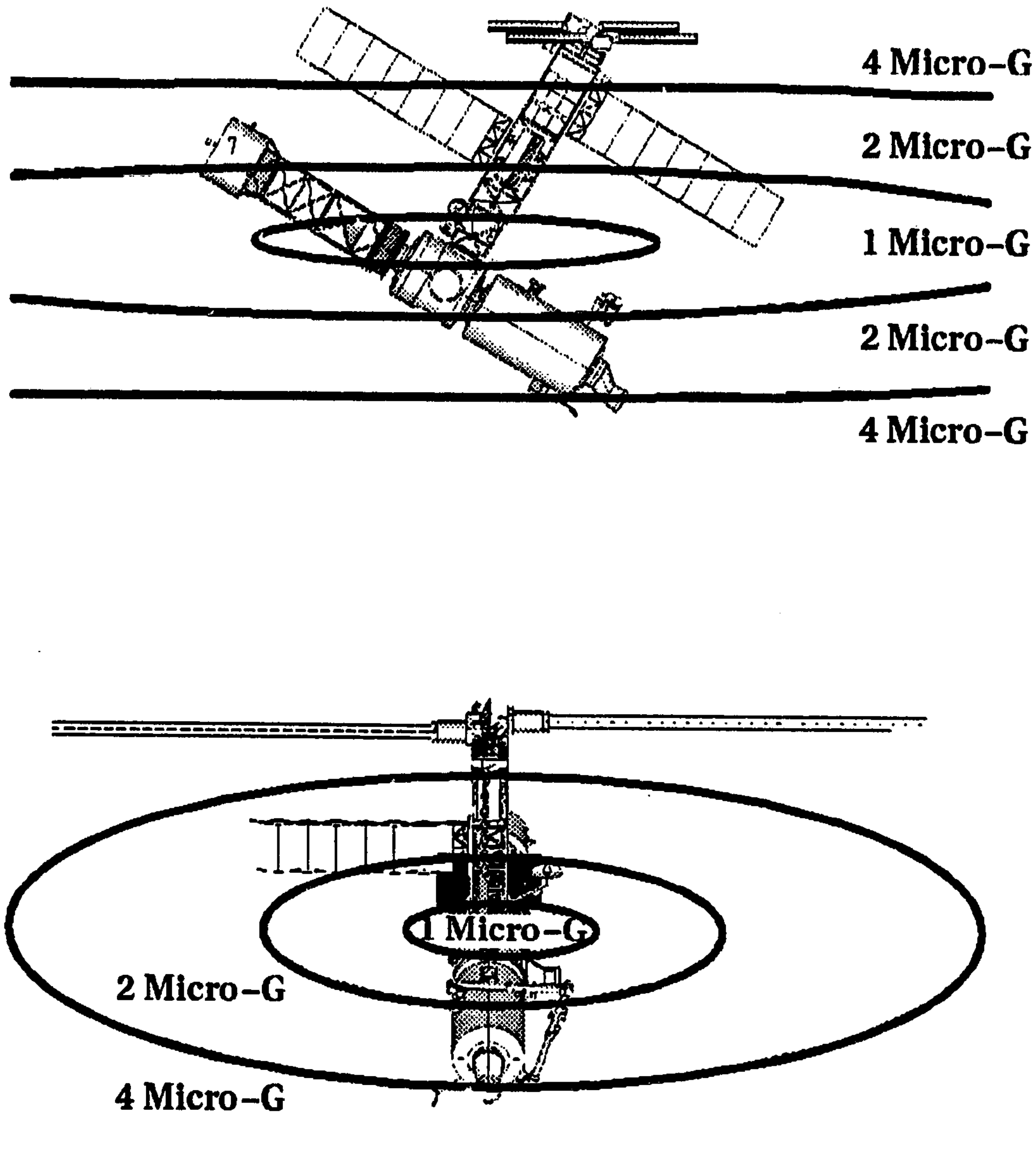


Figure 5.7.4-1 Stage 7 steady-state microgravity environment contours.

Table 5.7.4-2 summarizes the reboost lifetime characteristics of Stage 7 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 12.0 lbs/ft^2. The reboost was performed using the aft bus, which has a reboost efficiency of 100%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement. This stage violates the 90 day decay to 150 n.mi. lifetime requirement.

Table 5.7.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
215	236	1,416	5,976	N/A	57

The control characteristics of Stage 7 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.7.4-2. The CMGs were augmented with a 10,000 N-m-s momentum wheel. Table 5.7.4-3 summarizes the control characteristics depicted in the plots.

Table 5.7.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	0.0 degrees	-36.6 degrees	0.0 degrees	± 3.5 degrees	2800 N-m-s
w/STS	1.2 degrees	-32.2 degrees	0.2 degrees	± 0.3 degrees	3500 N-m-s

The control characteristics of Stage 7 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.7.4-3. No momentum wheels were required. Table 5.7.4-3 summarizes the control characteristics depicted in the plots.

5.7.5 Issues and Concerns

This stage violates the 90 day to 150 n.mi. altitude lifetime requirement.

This stage has a pitch flight attitude that exceeds ±15 degrees (with and without an attached Shuttle).

There is a possibility of some indirect plume impingement of the aft P6 radiator from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

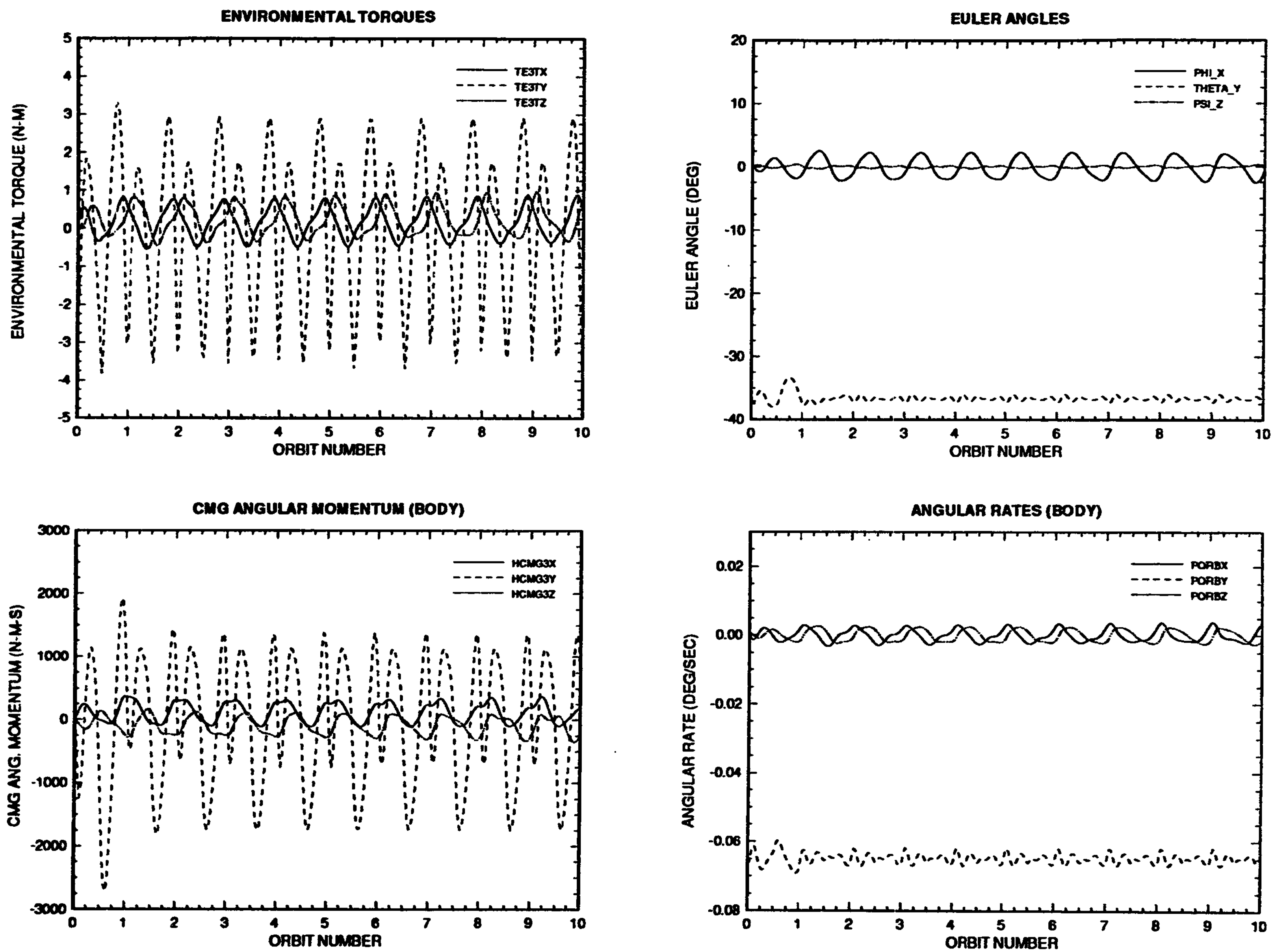


Figure 5.7.4-2 Stage 7 control plots without Shuttle attached.

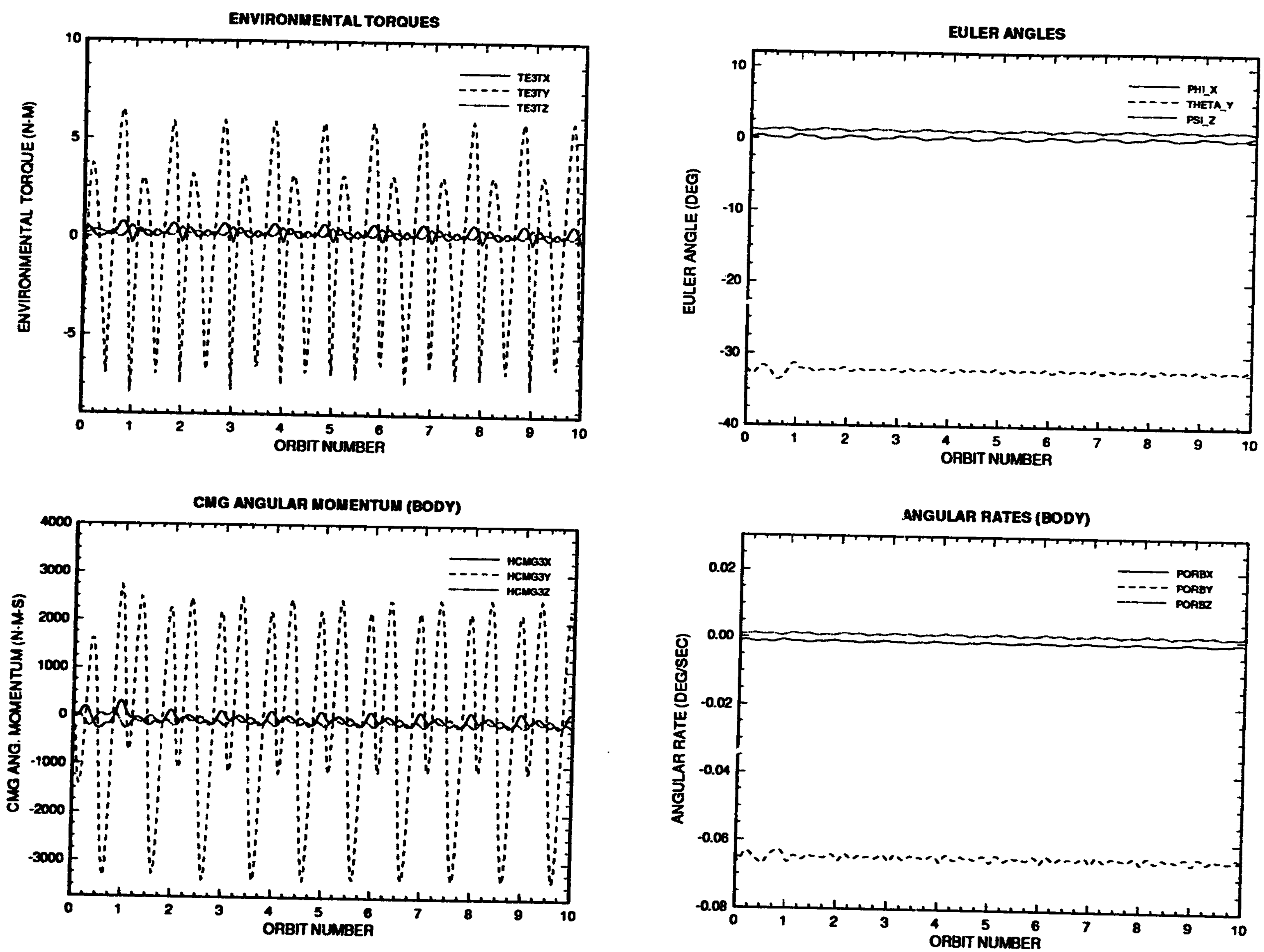


Figure 5.7.4-3 Stage 7 control plots with Shuttle attached.

5.8 Stage 8 Flight Characterization

5.8.1 Stage 8 - Flight 7A Shuttle Flight Manifest

The Shuttle delivers the airlock and its high pressure gas tanks. Table 5.8.1-1 lists the Shuttle Flight Manifest for Stage 8 - Flight 7A. The total mass of the station hardware to orbit is 21609 lbs and FSE mass of 4261 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 29298 lbs to 215 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a mission flight margin of 3428 lbs.

5.8.2 Stage 8 Configuration

Figure 5.8.2-1 displays the isometric view of Stage 8 after the Shuttle departs and the scheduled assembly is completed. Figure 5.8.2-2 shows the front, side, top and isometric views of Stage 8 with the Shuttle attached.

5.8.3 Flight 7A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 7 occurs along +V bar at an altitude of 215 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the forward Lab CBM in a tail down orientation.

Assembly Flight 7A is a 9 day mission with 2 EVAs. The SSRMS unberths the Airlock from the Shuttle payload bay and installs it on the Node 1 stbd port. The Airlock is then entered for completing the activation of the element and transferring the EMUs. The high pressure gas containers (2 each O2 and N2) located on the Unpressurized Logistics Carrier (ULC) are subsequently attached to the Airlock via combined EVA/EVR operations (Note: this requires two days of EVA).

Following separation, Stage 8 flight mode is LVLH with the Bus-1/Node section aligned along the velocity vector.

System Resource/Functionality

Stage 7 functionality, plus:

- Station based EVA capability

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*24 crew-hours*	
Resources Required:	*Power:*	*8,051 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		409 W	*(CSA)*
	Thermal:	*TBD W*	
	EVA:	*21:20 crew-hours*	

Table 5.8.1-1 Stage 8 - Flight 7A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
Airlock	18081	
Spacelab Pallets (SL-1 and SL-3)		3061
HP gas (O2 and N2)	3528	1200
subtotal	**21609**	**4261**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		500
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-1290
Misc. hardware	300	
Additional Attach Hardware	990	
	1290	
Variable Shuttle Consumables		-293
Food & Gear (-55 lbs/day over 6)	165	
5th N2 tanks (@128 lbs/N2)	128	
	293	
Middeck Lockers		-160
Generic Integrated Hardware		-5474
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER (2)	200	
Misc integration hardware	118	
Attach Hardware	990	
	5474	
Weight Growth Reserve		-1100
Maintenance Reserve		-570
Total Shuttle Lift Capability		**29298**

Mission Flight Margin		**3428**

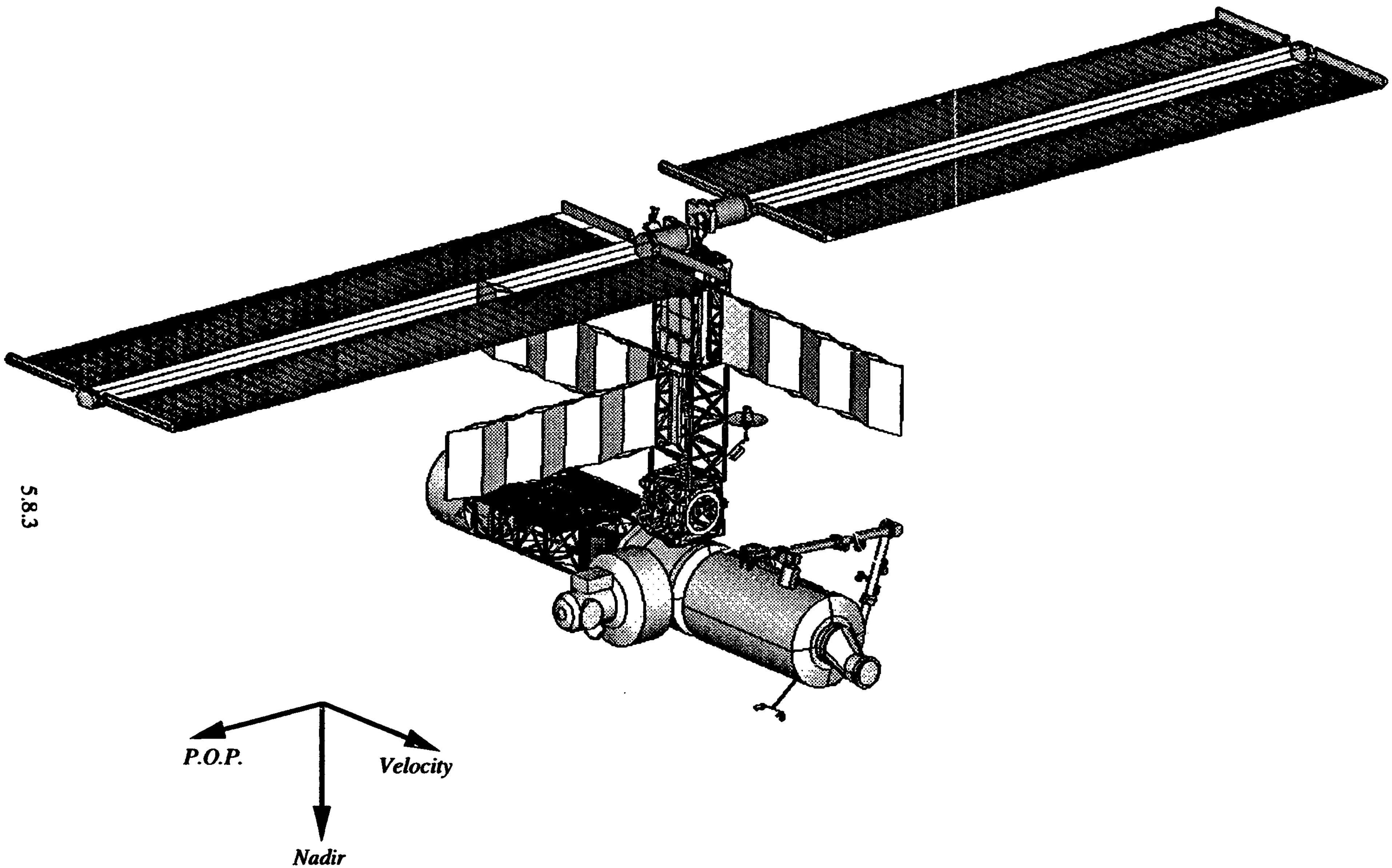


Figure 5.8.2–1 Stage 8 Configuration

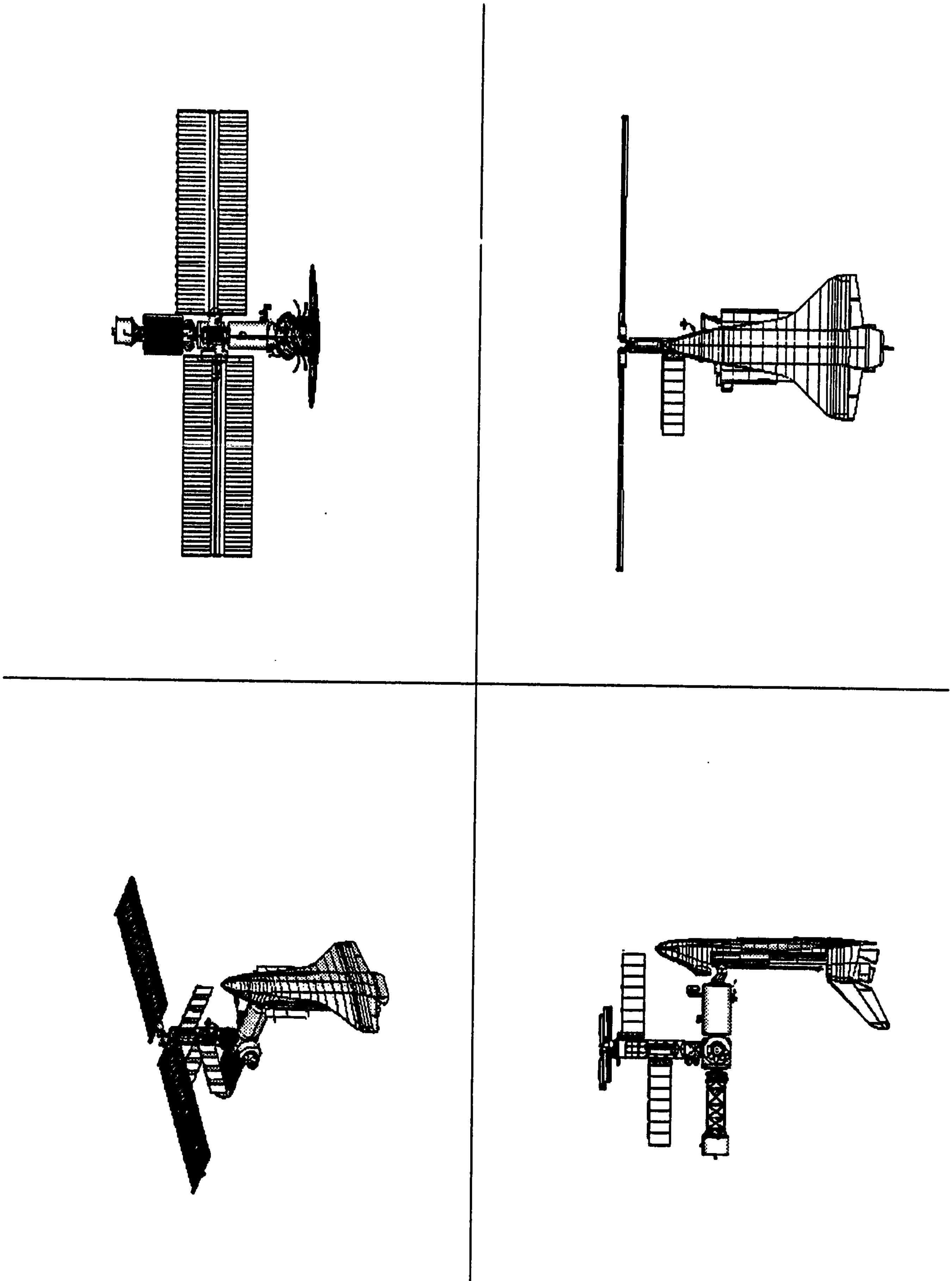


Figure 5.8.2-2 Stage 8 Configuration with Shuttle

5.8.4 Stage 8, Flight 7A Performance Characteristics

Stage 8, Flight 7A is assembled at a 215 n.mi. altitude in an LVLH flight mode with 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is April, 1999.

The Stage 8 microgravity environment is depicted in figure 5.8.4-1. In a +2σ atmosphere (solar flux = 245.2, geomagnetic index = 19.0) this stage has a flight attitude of yaw = 0, pitch = -38.7, and roll = 0. Table 5.8.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. For this configuration there are no ISPR racks in the 1 μg environment.

Table 5.8.4-1 Stage 8 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	3.2
LAS-2	ISPR	2.9
LAS-3	ISPR	2.6
LAS-4	ISPR	2.3
LAS-5	SYS	2.1
LAS-6	SYS	1.8
LAF-1	SYS	3.6
LAF-2	SYS	3.4
LAF-3	SYS	3.1
LAF-4	SYS	2.8
LAF-5	SYS	2.5
LAF-6	SYS	2.2
LAP-1	ISPR	3.2
LAP-2	ISPR	2.9
LAP-3	ISPR	2.6
LAP-4	ISPR	2.3
LAP-5	SYS	2.1
LAP-6	SYS	1.8
LAC-1	ISPR	2.7
LAC-2	ISPR	2.4
LAC-3	ISPR	2.1
LAC-4	ISPR	1.9
LAC-5	ISPR	1.6
LAC-6	SYS	1.4

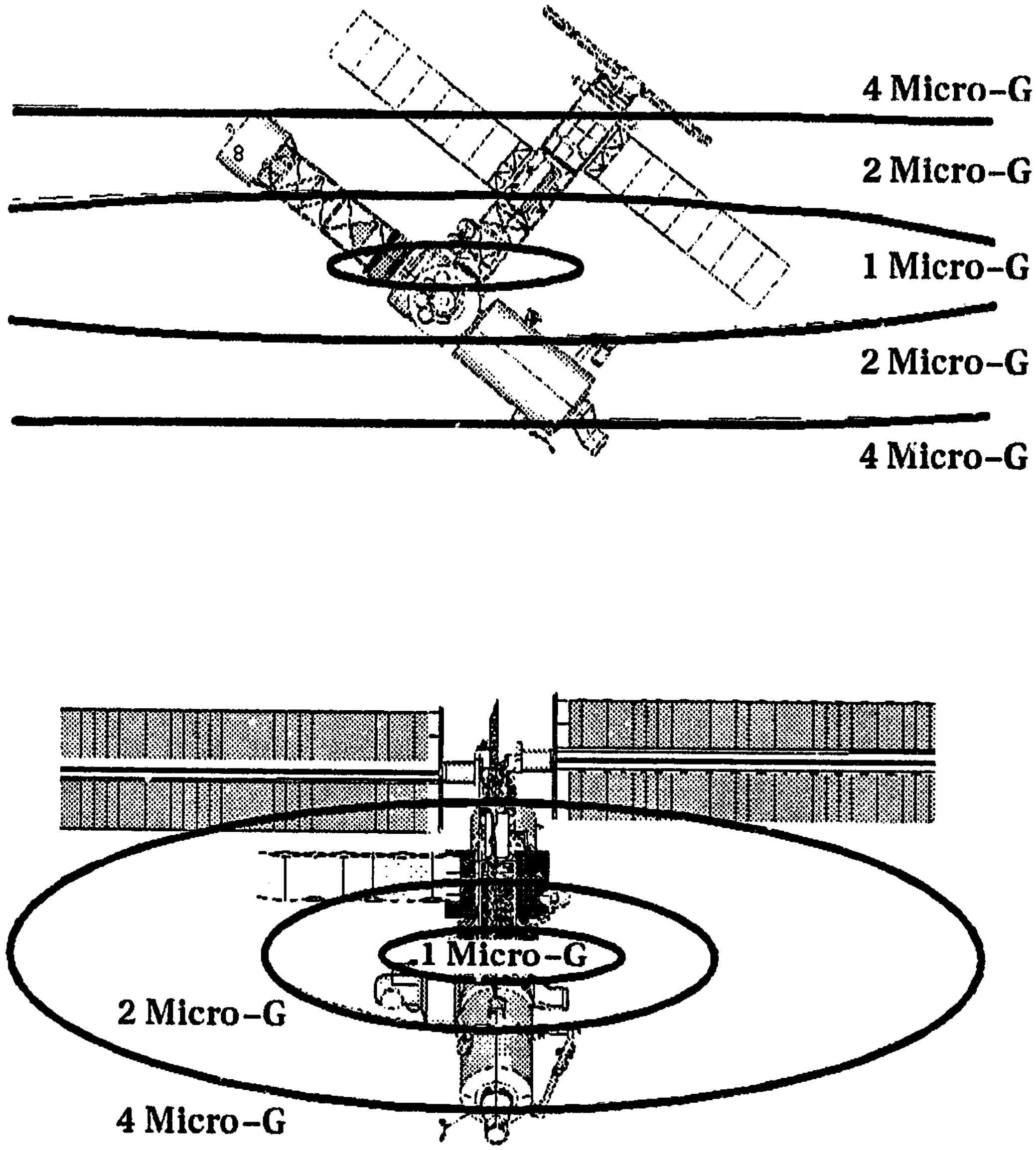


Figure 5.8.4-1 Stage 8 steady-state microgravity environment contours.

Table 5.8.4-2 summarizes the reboost lifetime characteristics of Stage 8 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 12.9 lbs/ft^2. The reboost was performed using the aft bus, which currently has a reboost efficiency of 100%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement. This stage violates the 90 day decay to 150 n.mi. lifetime requirement.

Table 5.8.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
215	235	1,521	4,455	N/A	65

The control characteristics of flight 7A under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.8.4-2. The CMGs were augmented with a 10,000 N-m-s momentum wheel. Table 5.8.4-3 summarizes the control characteristics depicted in the plots.

Table 5.8.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	0.0 degrees	-43.7 degrees	0.0 degrees	± 3.1 degrees	3300 N-m-s
w/STS	1.4 degrees	-32.5 degrees	0.6 degrees	± 0.3 degrees	4500 N-m-s

The control characteristics of Stage 8 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.8.4-3. No momentum wheels were required. Table 5.8.4-3 summarizes the control characteristics depicted in the plots.

5.8.5 Issues and Concerns

This stage violates the 90 day to 150 n.mi. altitude lifetime requirement.

This stage has a pitch flight attitude that exceeds ±15 degrees (with and without an attached Shuttle).

There is a possibility of some indirect plume impingement of the aft P6 radiator from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

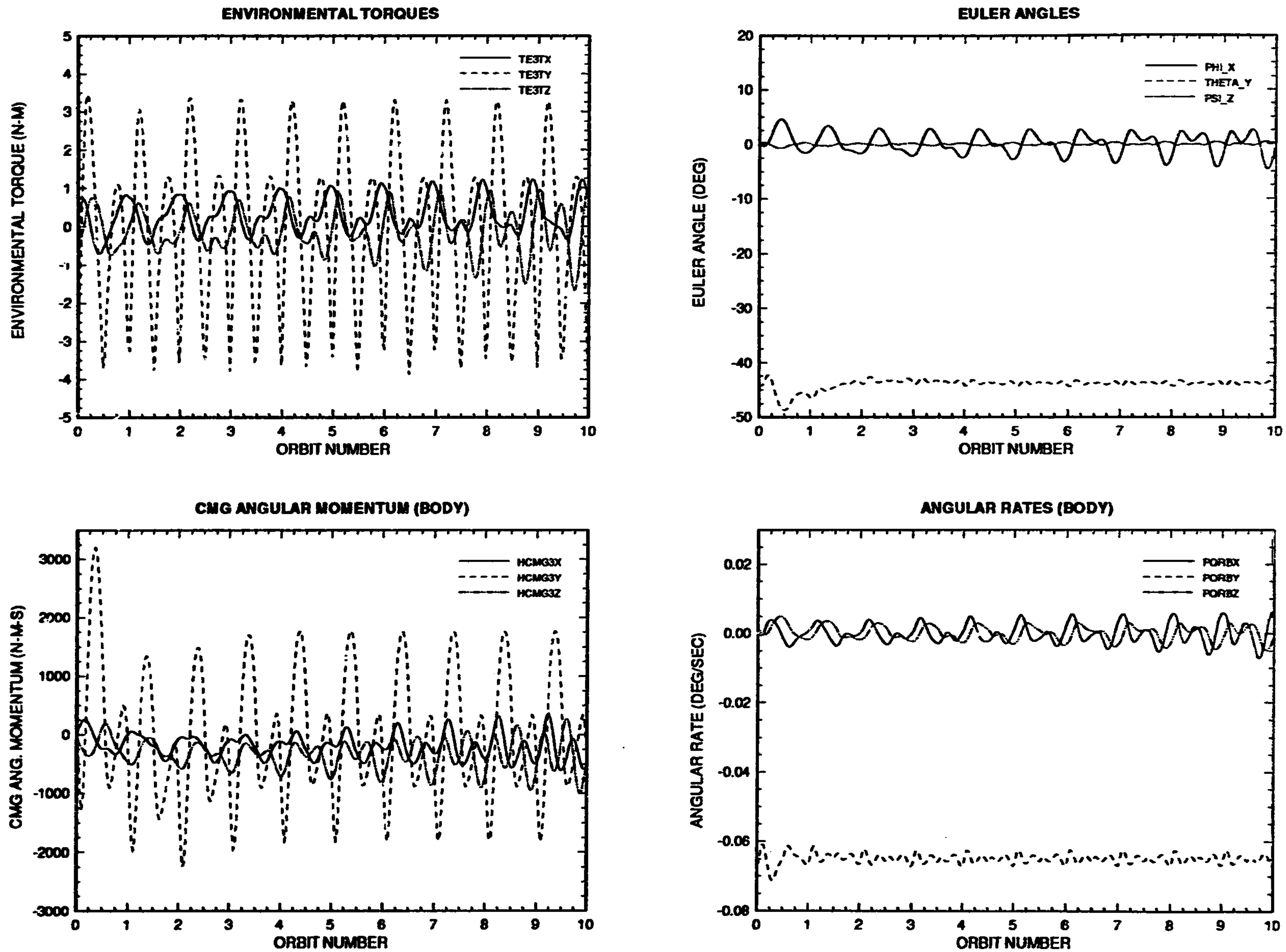


Figure 5.8.4-2 Stage 8 control plots without Shuttle attached.

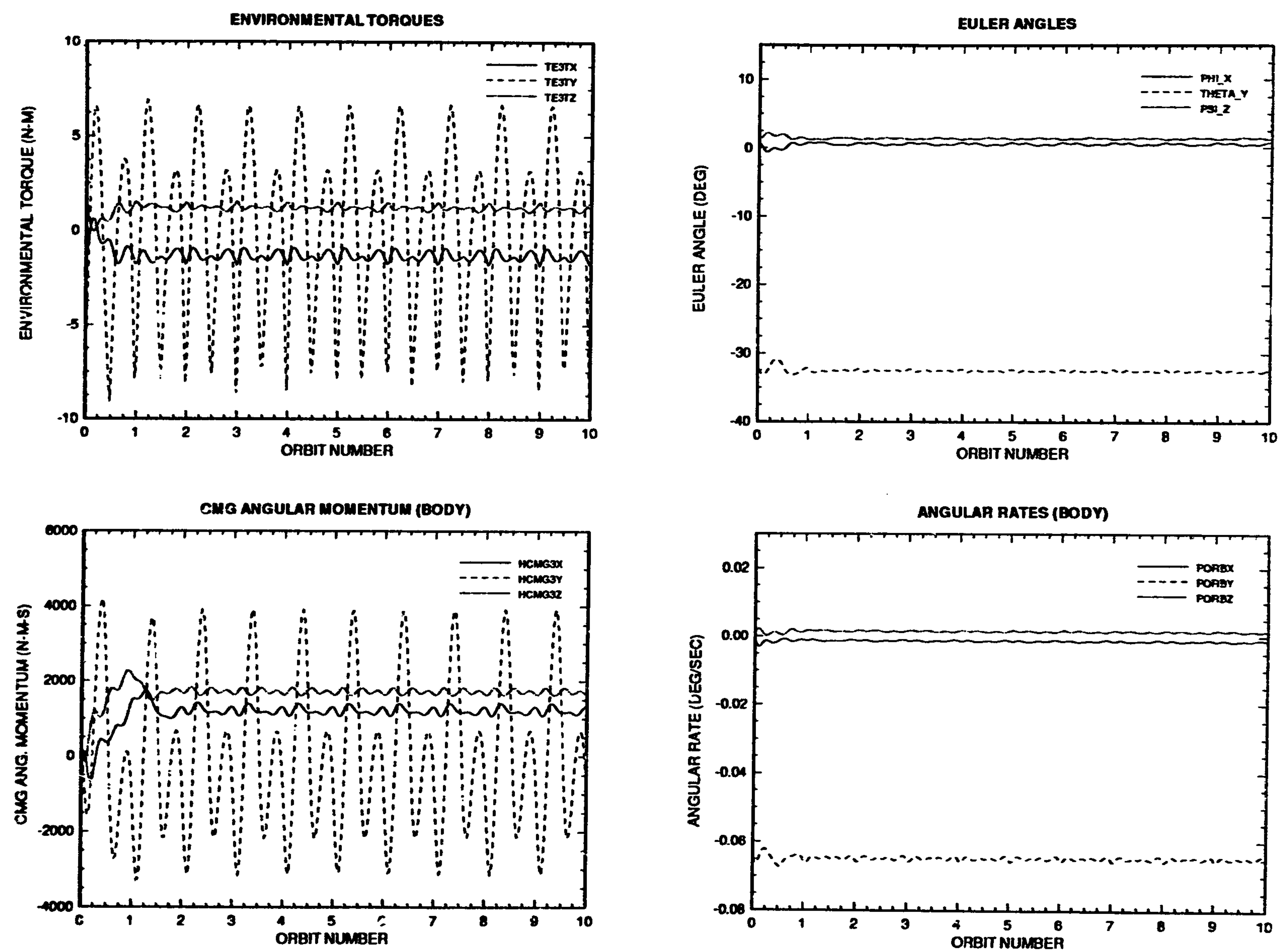


Figure 5.8.4-3 Stage 8 control plots with Shuttle attached.

5.9 Stage 9 Flight Characterization

5.9.1 Stage 9 - Flight 8A Shuttle Flight Manifest

The Shuttle delivers the S0 segment. Table 5.9.1-1 lists the Shuttle Flight Manifest for Stage 9 - Flight 8A. The total mass of the station hardware to orbit is 30205 lbs. The second section of the table shows the Shuttle Performance and hardware/ consumables required for the mission resulting in the net Shuttle Lift Capability of 30790 lbs to 215 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 585 lbs.

5.9.2 Stage 9 Configuration

Figure 5.9.2-1 displays the isometric view of Stage 9 after the Shuttle departs and the scheduled assembly is completed. Figure 5.9.2-2 shows the front, side, top and isometric views of Stage 9 with the Shuttle attached.

5.9.3 Flight 8A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 8 occurs along +V bar at an altitude of 215 n.m. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the forward Lab CBM in a tail down orientation.

Flight 8A is a 7 day mission with 2 EVAs. The SRMS removes the S0 ITS from the payload bay and hands it over to the SSRMS, based on the Lab PDGF. The SSRMS attaches the S0 ITS to the Lab cradle assembly (LCA) and the forward and aft S0 MTS struts are installed on the Lab. During EVA operations, umbilicals are connected, and preparations for activating the Mobile Transporter (MT) are begun. Several pieces of equipment (i.e., EV-CPS, PWP, airlock spur, etc.) are left in the stowed configuration on the S0 ITS for installation on the next assembly flight.

Following separation, Stage 9 flight mode is LVLH with the Bus-1/Node section aligned along the velocity vector.

System Resource/Functionality

Stage 8 functionality, plus:

- Delivers and installs S0 using the Lab Cradle Assembly
- S0 MBSUs and DDCUs connected but inoperative
- Attitude and attitude rate determination provided by station and Bus-1

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*24 crew-hours*	
Resources Required:	*Power:*	*8,679 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		409 W	*(CSA)*
	Thermal:	*TBD W*	
	EVA:	*22:10 crew-hours*	

Table 5.9.1-1 Stage 9 - Flight 8A Shuttle Flight Manifest

Hardware	**Mass (lbs)**	**FSE**
S0 Structure	14774	
S0 UTILITY TRAYS	4410	
S0 AVIONICS	718	
S0 DDCU	625	
MBSU	1582	
HAB UMBILICALS	371	
NODE UMBILICALS	1956	
LAB UMBILICALS	586	
MT UMBILICAL SPOOLS	908	
MODULE-TRUSS BARS	1104	
GPS ANTENNA	53	
PLASMA CONT & SUPP	692	
PWP-A	216	
PWP-B	216	
CETA SPUR	85	
EVA LIGHTS	168	
Mobile Transporter	1740	
subtotal	**30205**	**0**

Shuttle Performance		**Mass (lbs)**
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		500
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-238
Misc. hardware	238	
	238	
Variable Shuttle Consumables		-183
Food & Gear (-55 lbs/day over 6)	55	
5th N2 tanks (@128 lbs/N2)	128	
	183	
Middeck Lockers		-200
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-400
Total Shuttle Lift Capability		**30790**

Mission Flight Margin		**585**

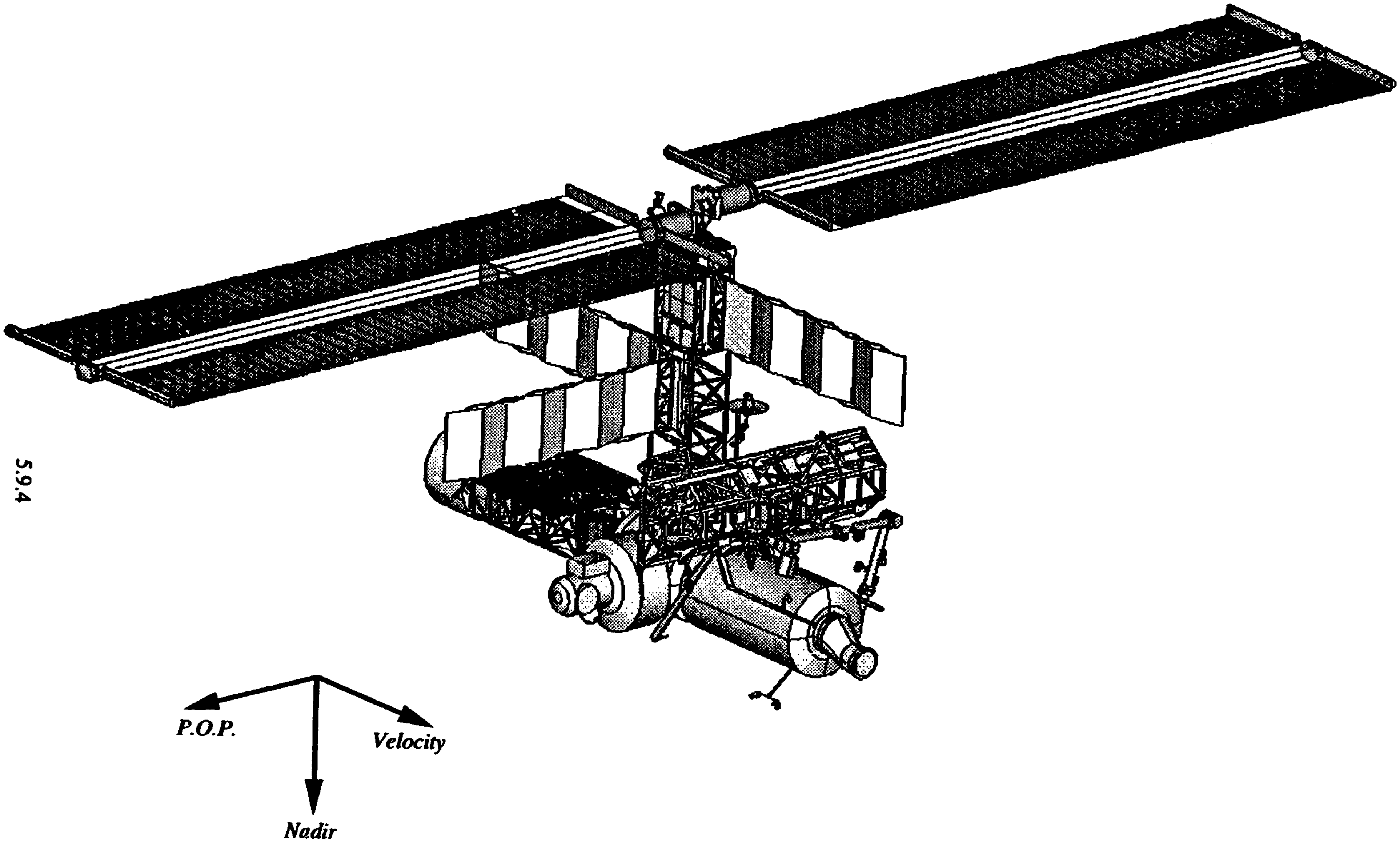


Figure 5.9.2-1 Stage 9 Configuration

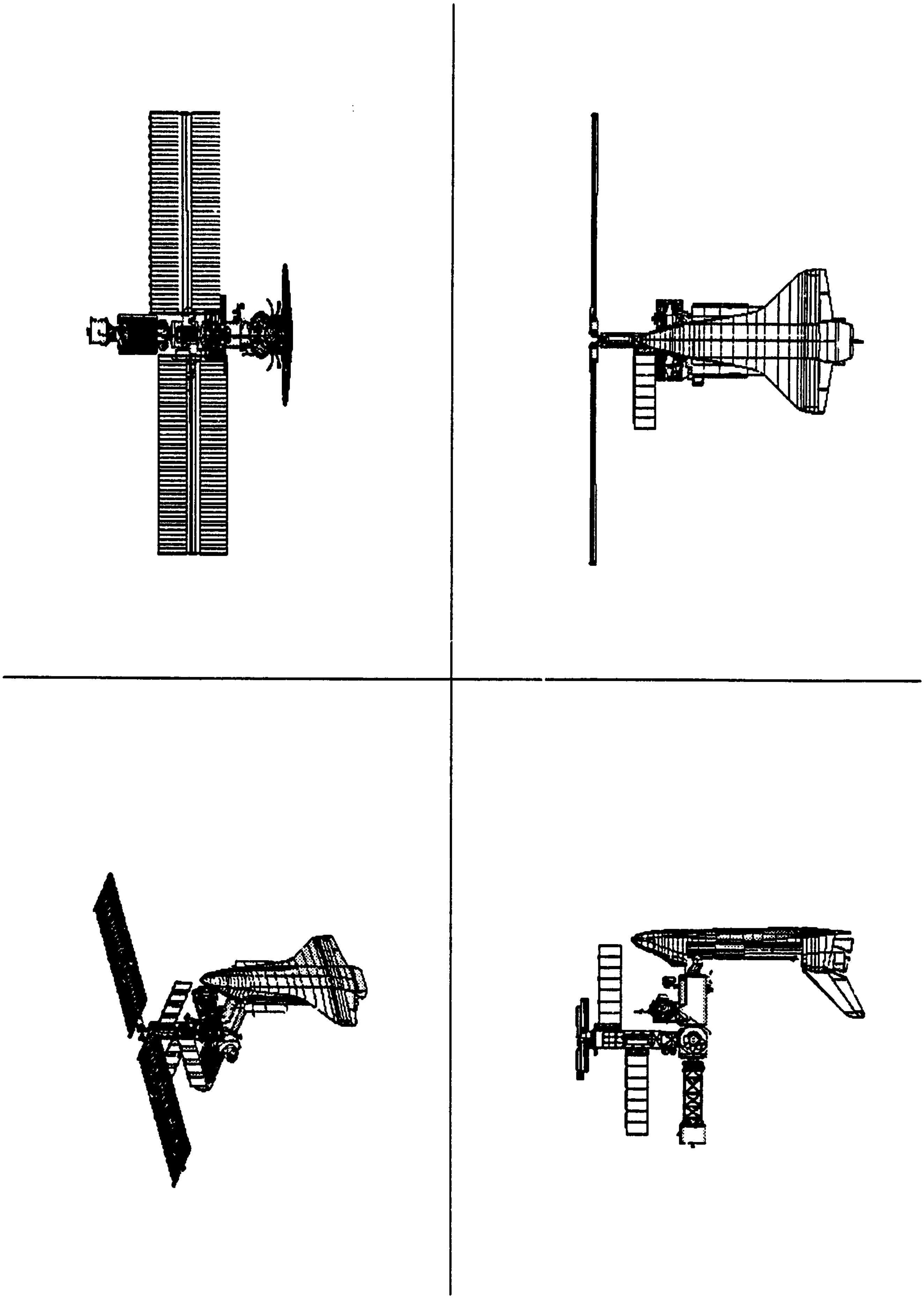


Figure 5.9.2-2 Stage 9 Configuration with Shuttle

5.9.4 Stage 9, Flight 8A Performance Characteristics

Stage 9, Flight 8A is assembled at a 215 n.mi. altitude in an LVLH flight mode with 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is June, 1999.

The Stage 9 steady state microgravity environment is depicted in figure 5.9.4-1. In a +2σ atmosphere (solar flux = 243.3, geomagnetic index = 18.6) this stage has a flight attitude of yaw = 0, pitch = -30.7, and roll = 0. Table 5.9.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2 sigma atmosphere. For this configuration there are no ISPR racks in the 1 μg environment.

Table 5.9.4-1 Stage 9 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	2.7
LAS-2	ISPR	2.5
LAS-3	ISPR	2.3
LAS-4	ISPR	2.1
LAS-5	SYS	1.8
LAS-6	SYS	1.6
LAF-1	SYS	3.3
LAF-2	SYS	3.0
LAF-3	SYS	2.8
LAF-4	SYS	2.6
LAF-5	SYS	2.3
LAF-6	SYS	2.1
LAP-1	ISPR	2.7
LAP-2	ISPR	2.5
LAP-3	ISPR	2.3
LAP-4	ISPR	2.1
LAP-5	SYS	1.8
LAP-6	SYS	1.6
LAC-1	ISPR	2.2
LAC-2	ISPR	2.0
LAC-3	ISPR	1.8
LAC-4	ISPR	1.5
LAC-5	ISPR	1.3
LAC-6	SYS	1.2

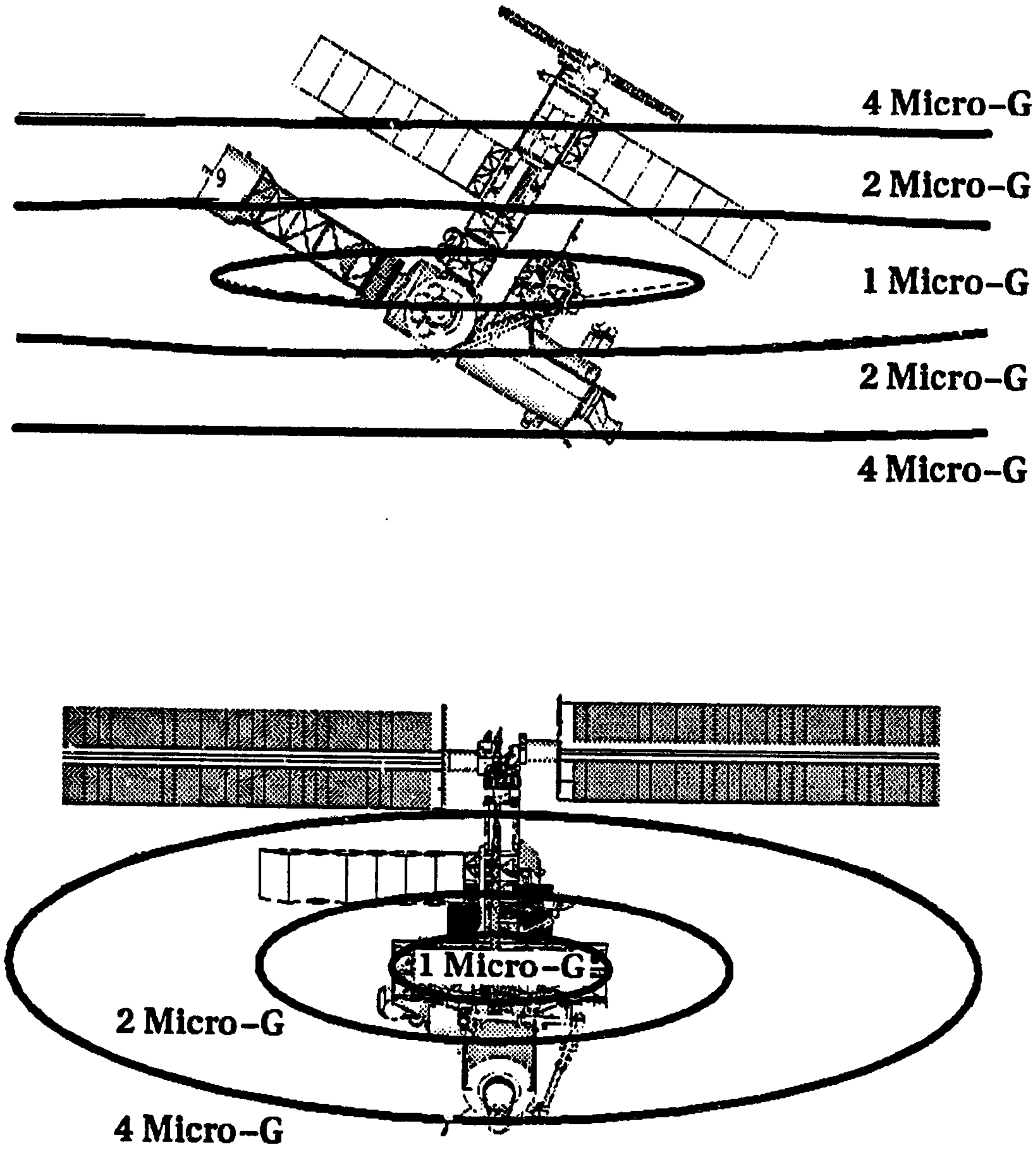


Figure 5.9.4-1 Stage 9 steady-state microgravity environment contours.

Table 5.9.4-2 summarizes the reboost lifetime characteristics of Stage 9 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 14.4 lbs/ft^2. The reboost was performed using the aft bus, which currently has a reboost efficiency of 100%. For this stage there is insufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement. This stage violates the 90 day decay to 150 n.mi. lifetime requirement.

Table 5.9.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
215	230	1,372	3,084	N/A	83

The control characteristics of Stage 9 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.9.4-2. The CMGs were augmented with a 4000 N-m-s momentum wheel. Table 5.9.4-3 summarizes the control characteristics depicted in the plots.

Table 5.9.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	0.0 degrees	-35.5 degrees	0.0 degrees	± 3.5 degrees	4300 N-m-s
w/STS	1.4 degrees	-32.4 degrees	-0.6 degrees	± 0.2 degrees	4700 N-m-s

The control characteristics of Stage 9 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.9.4-3. No momentum wheels were required. Table 5.9.4-3 summarizes the control characteristics depicted in the plots.

5.9.5 Issues and Concerns

This stage violates the 90 day to 150 n.mi. altitude lifetime requirement.

For this stage there is insufficient propellant reserve on the bus to meet the skip cycle contingency reboost requirement. Increases in assembly altitude (requiring additional shuttle lift performance), increased bus fuel capacity or manifesting a replacement bus sooner in the assembly sequence could resolve this issue.

There is a possibility of some indirect plume impingement of the aft P6 radiator from the aft bus attitude control thrusters.

This stage has a pitch flight attitude that exceeds ±15 degrees (with and without an attached Shuttle).

This stage does not provide a good microgravity environment.

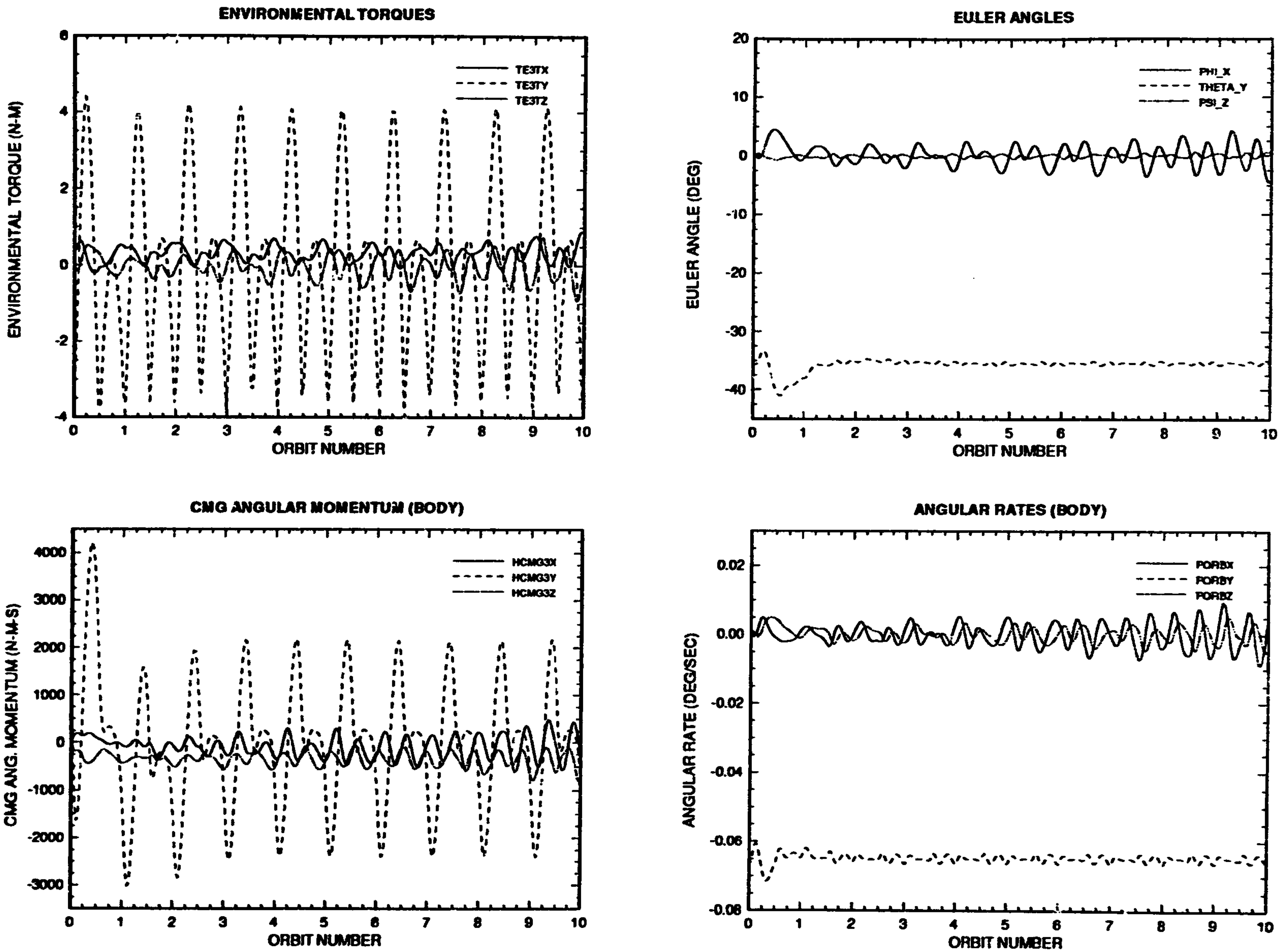


Figure 5.9.4-2 Stage 9 control plots without Shuttle attached.

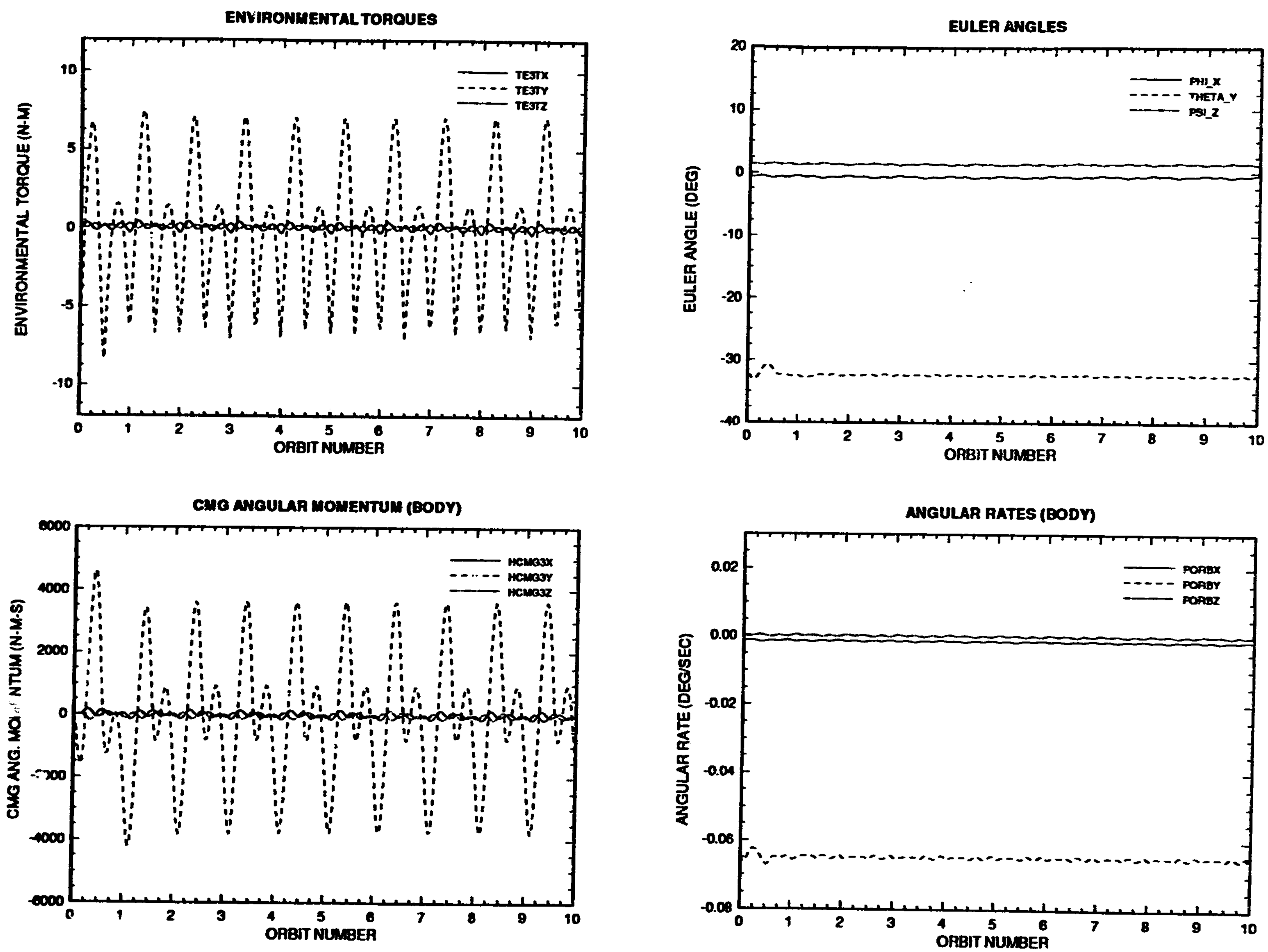


Figure 5.9.4-3 Stage 9 control plots with Shuttle attached.

5.10 Stage 10 Flight Characterization

5.10.1 Stage 10 - Zenith Bus-1 Flight Shuttle Flight Manifest

The Shuttle delivers the zenith Bus-1. Table 5.10.1-1 lists the Shuttle Flight Manifest for Stage 10 - Zenith Bus-1 Flight. The total mass of the station hardware to orbit is 28256 lbs. The second section of the table shows the Shuttle Performance and hardware/ consumables required for the mission resulting in the net Shuttle Lift Capability of 30464 lbs to 215 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 2208 lbs.

5.10.2 Stage 10 Configuration

Figure 5.10.2-1 displays the isometric view of Stage 10 after the Shuttle departs and the scheduled assembly is completed. Figure 5.10.2-2 shows the front, side, top and isometric views of Stage 10 with the Shuttle attached.

5.10.3 Zenith Bus-1 Flight Assembly Operations Description

Rendezvous of the Shuttle with the Stage 9 occurs along +V bar at an altitude of 215 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the forward Lab CBM in a tail down orientation.

The zenith Bus-1 flight is a 9 day mission with 3 EVAs. The SSRMS is positioned on the PDGF located at (0, -4.1,-2.108) meters on the S0 ITS. The SRMS removes the zenith pre-integrated stinger and bus from the Shuttle payload bay and hands it over to the SSRMS. The SSRMS then installs the zenith Bus and stinger on the zenith face of the P6 ITS, and EVA crew members connect the Bus-1-to-Z1 umbilicals (See figure 5.10.3-1 for a graphical depiction of these operations). EVA/EVR operations involved removing the S0 port and starboard keel pins/drag links, installing the Node 1 to S0 umbilical tray and the airlock spur, and stowing the LCA umbilicals (EVA tasks remaining from the previous assembly flight).

Following separation, Stage 10 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

Figures 5.10.3-2 and 5.10.3-3 are included to demonstrate the feasibility of replacing the Bus-1 at either location, although it is anticipated that these tasks will not be required at this stage. Figure 5.10.3-2 is a graphical depiction of the following installation maneuvers required to replace the Bus-1 located aft of Node 1: 1) relocate the SSRMS on the aft stinger grapple fixture; 2) grapple the "spent" Bus-1 with the SSRMS and hand it to the SRMS; 3) using the SRMS, place the "spent" Bus-1 in the Shuttle payload bay, and grapple the replacement Bus-1; 4) hand-off the Bus-1 from the SRMS to the SSRMS; and, 5) install the replacement Bus-1 on the stinger. Figure 5.10.3-3 is a graphical depiction of the similar installation maneuvers required to replace the Bus-1 located in the -Z location above the Z1 truss.

System Resource/Functionality

This flight delivers the second Bus-1 providing redundant systems capability with the first one.

- MT powered from TUS
- External radiation monitoring

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*36 crew-hours*	
Resources Required:	*Power:*	*8,679 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		409 W	*(CSA)*
	Thermal:	*TBD W*	
	EVA:	*28:40 crew-hours*	

Table 5.10.1-1 Stage 10 - Zenith Bus-1 Flight Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
Bus-1	25000	
zenith spacer truss	3256	
subtotal	**28256**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		500
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-238
Misc. hardware	238	
	238	
Variable Shuttle Consumables		-549
Food & Gear (-55 lbs/day over 6)	165	
5th, 6th & 7th N2 Tank (@128 lbs/tank)	384	
	549	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-400
Total Shuttle Lift Capability		**30464**

Mission Flight Margin		**2208**

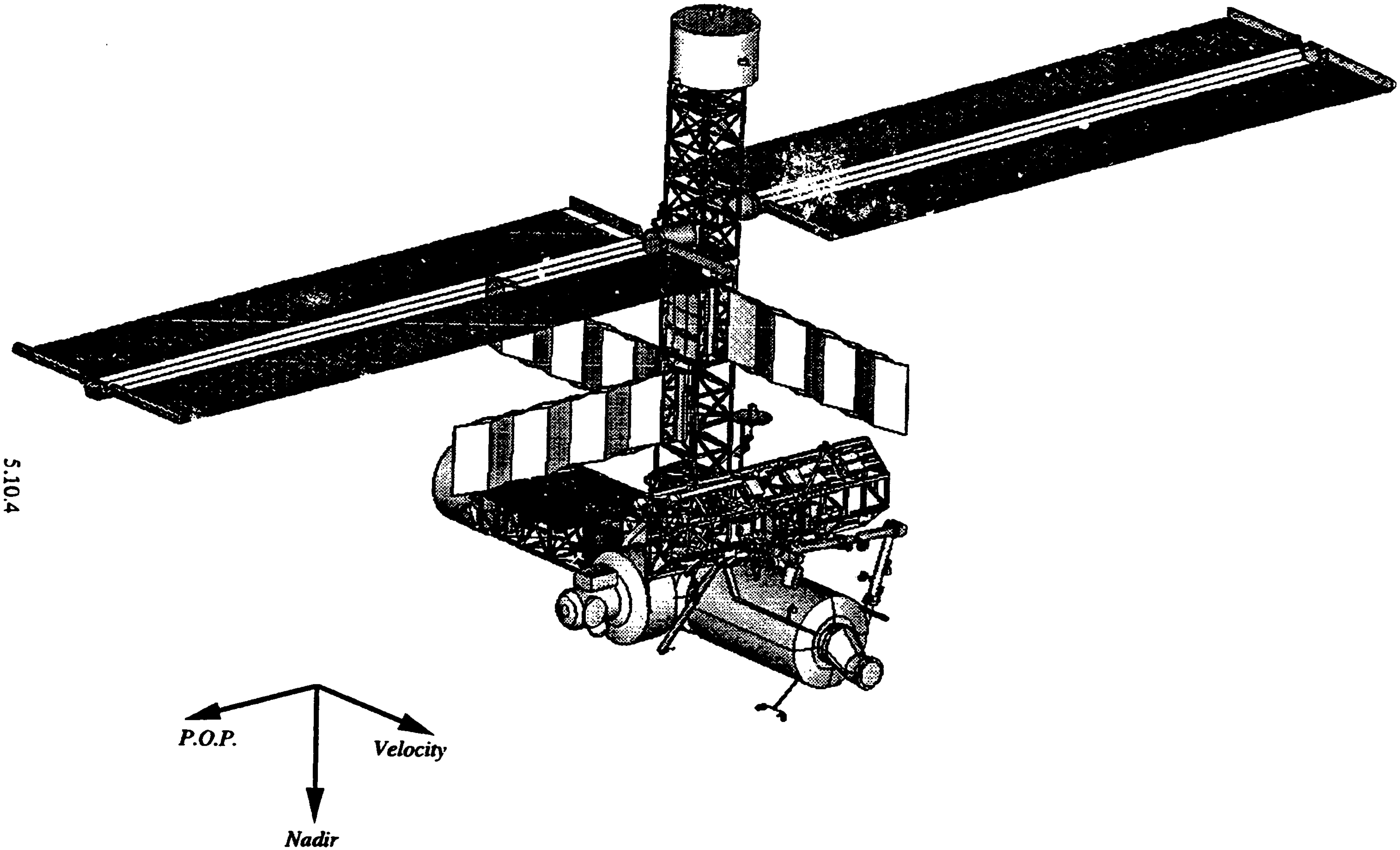


Figure 5.10.2-1 Stage 10 Configuration

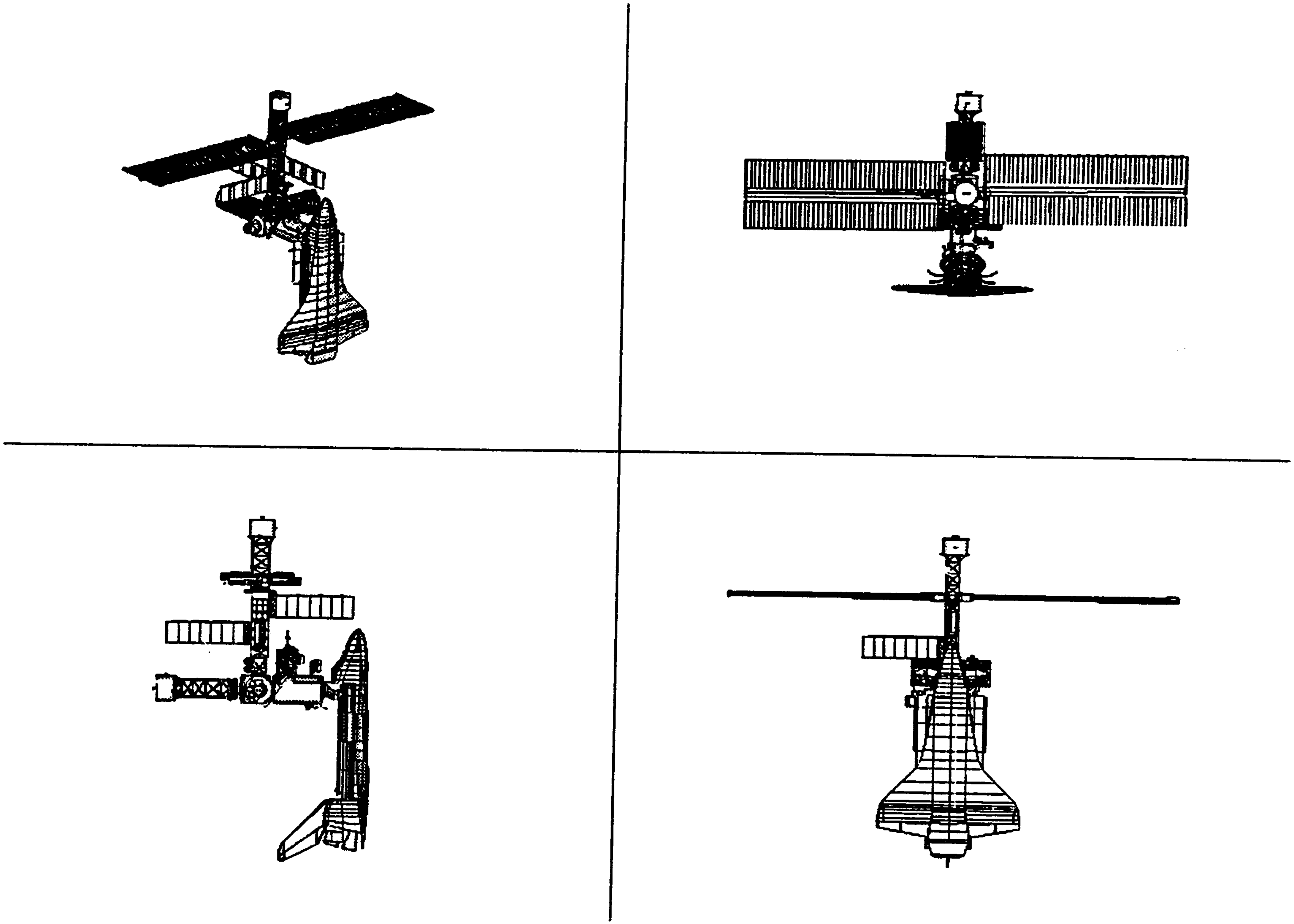


Figure 5.10.2-2 Stage 10 Configuration with Shuttle

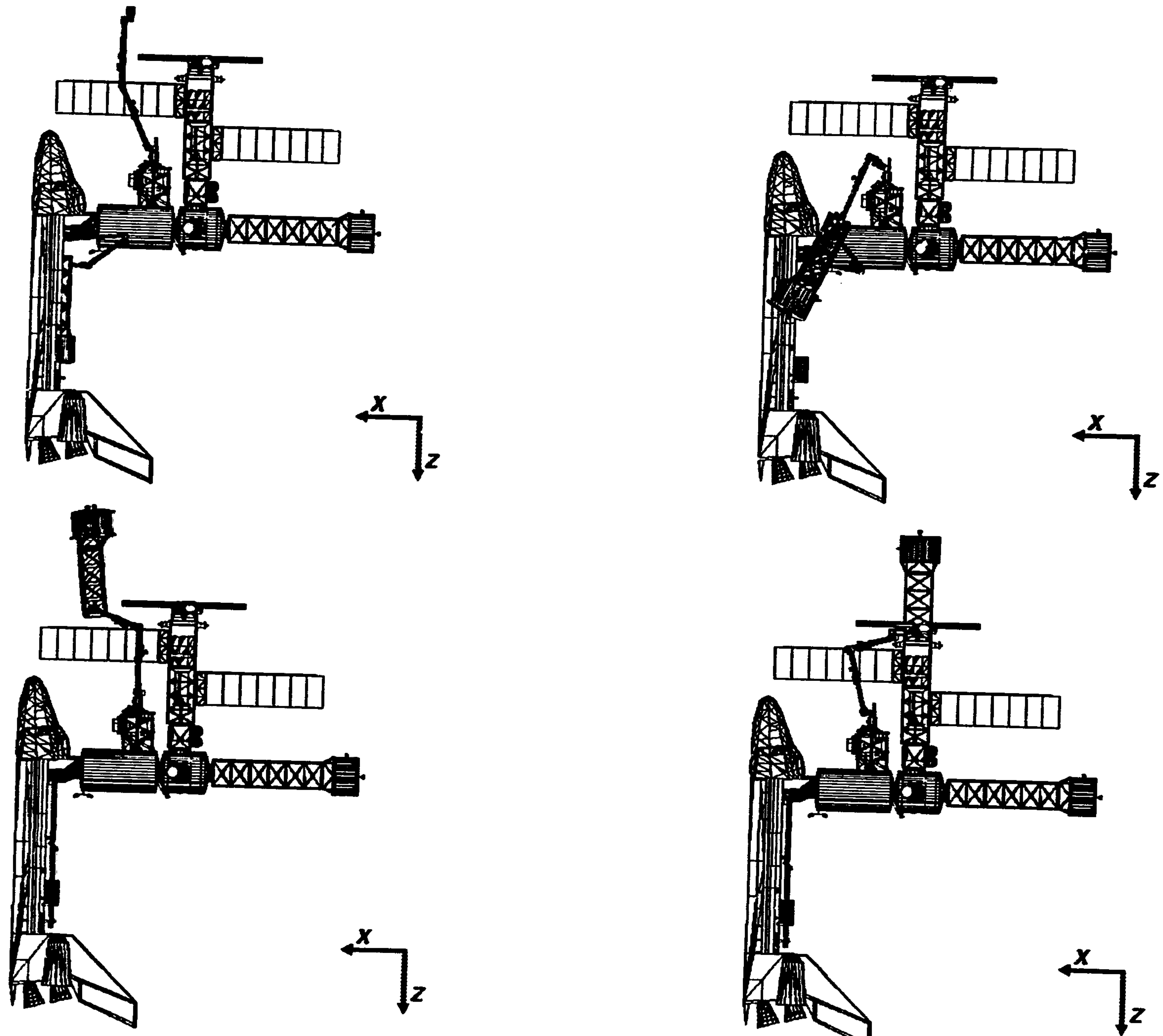


Figure 5.10.3–1 Installation of zenith bus and extender.

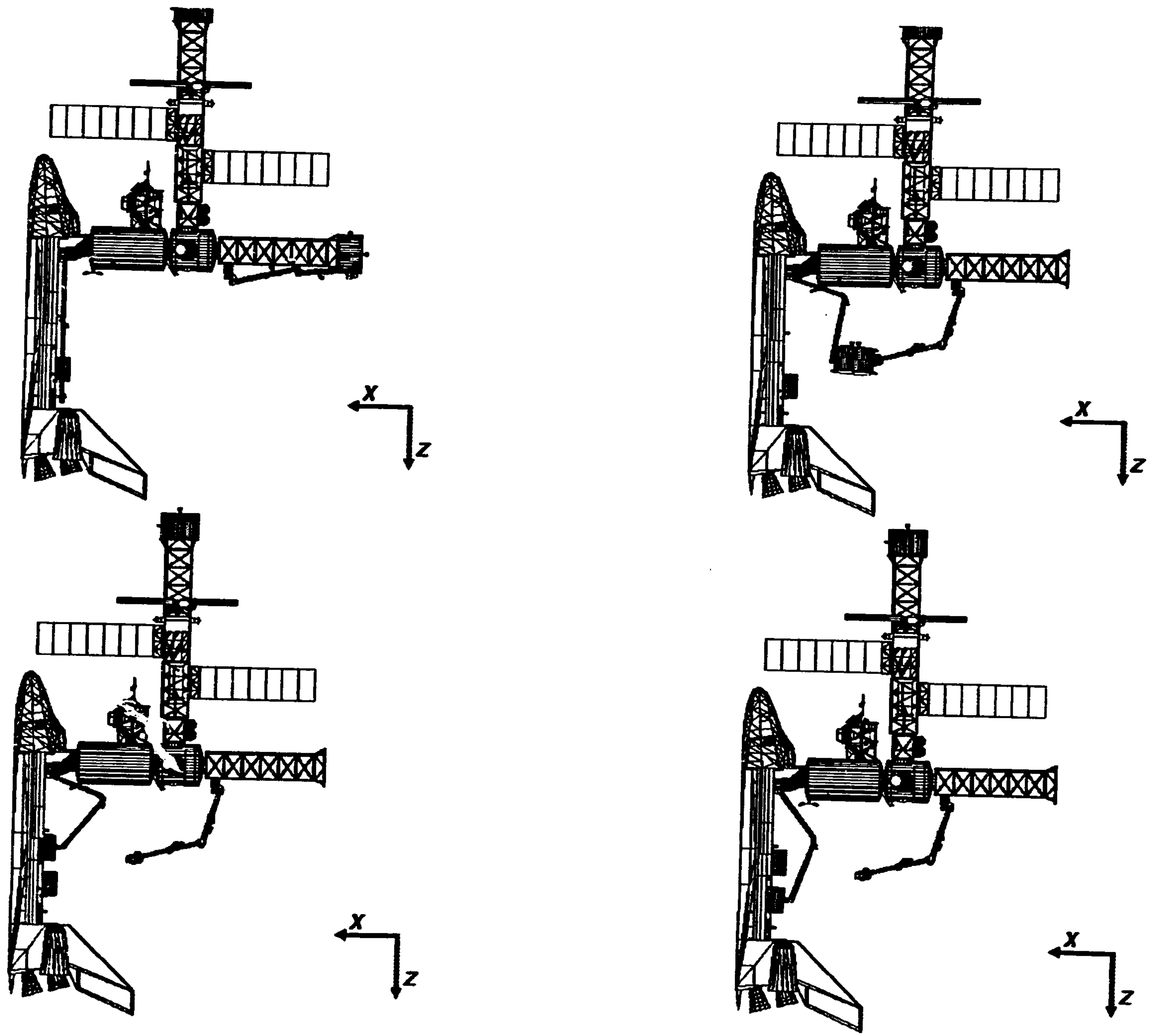


Figure 5.10.3–2 Aft bus replacement operations.

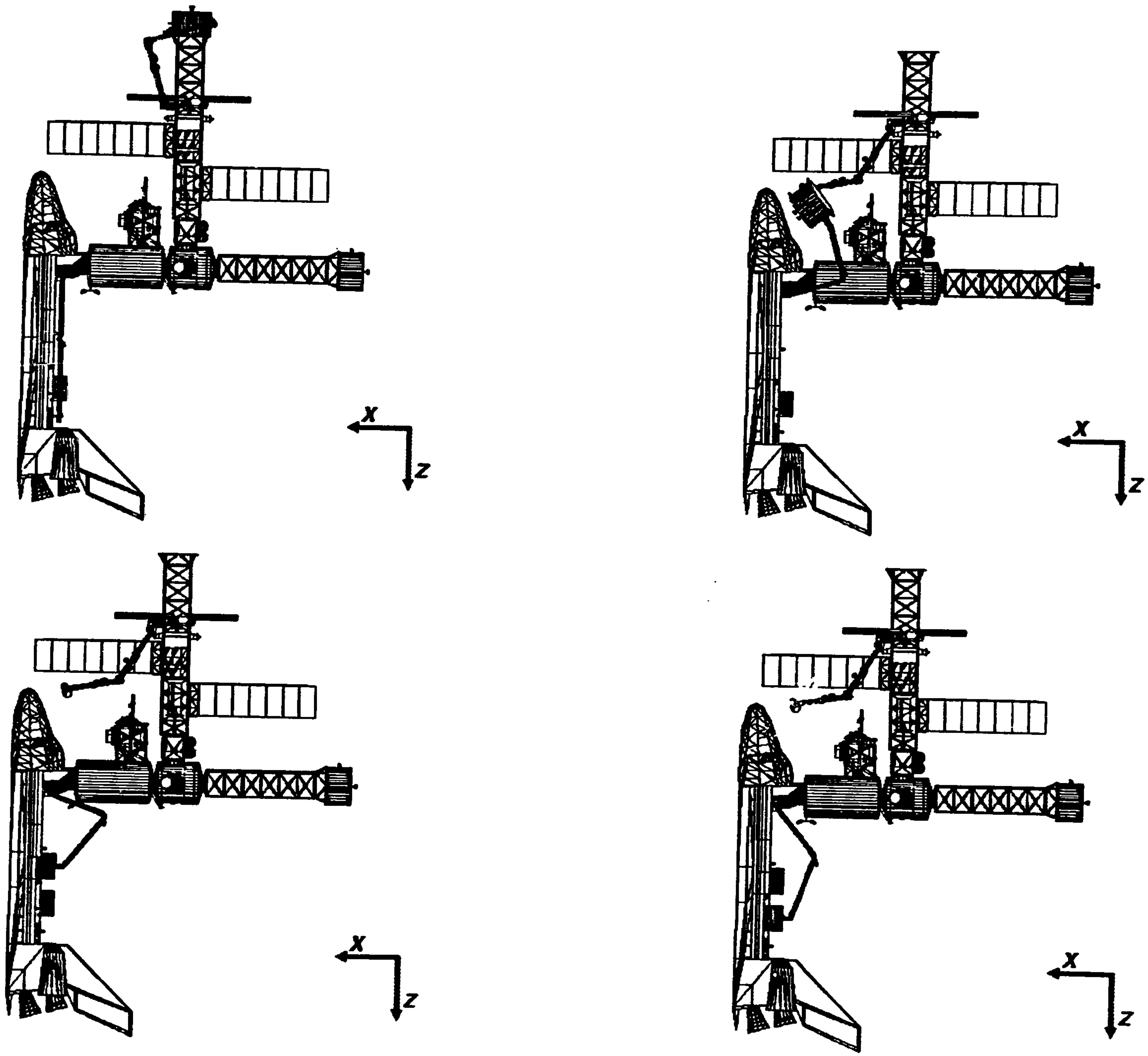


Figure 5.10.3–3 Zenith bus replacement operations.

5.10.4 Stage 10, Zenith Bus Flight Performance Characteristics

Stage 10 is assembled at a 215 n.mi. altitude in an LVLH flight mode with 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is August, 1999.

The Stage 10 steady state microgravity environment is depicted in figure 5.10.4-1. In a $+2\sigma$ atmosphere (solar flux = 245.7, geomagnetic index = 18.3) this stage has a flight attitude of yaw = 0.6, pitch = 16.1, and roll = 2.1. Table 5.10.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given $+2\sigma$ atmosphere. This configuration contains 7 ISPR racks in the 1 μg environment.

Table 5.10.4-1 Stage 10 US Lab Racks Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.0
LAS-2	ISPR	1.2
LAS-3	ISPR	1.3
LAS-4	ISPR	1.4
LAS-5	SYS	1.6
LAS-6	SYS	1.7
LAF-1	SYS	1.6
LAF-2	SYS	1.7
LAF-3	SYS	1.8
LAF-4	SYS	2.0
LAF-5	SYS	2.1
LAF-6	SYS	2.2
LAP-1	ISPR	1.0
LAP-2	ISPR	1.1
LAP-3	ISPR	1.3
LAP-4	ISPR	1.4
LAP-5	SYS	1.5
LAP-6	SYS	1.7
LAC-1	ISPR	0.5
LAC-2	ISPR	0.6
LAC-3	ISPR	0.7
LAC-4	ISPR	0.8
LAC-5	ISPR	1.0
LAC-6	SYS	1.1

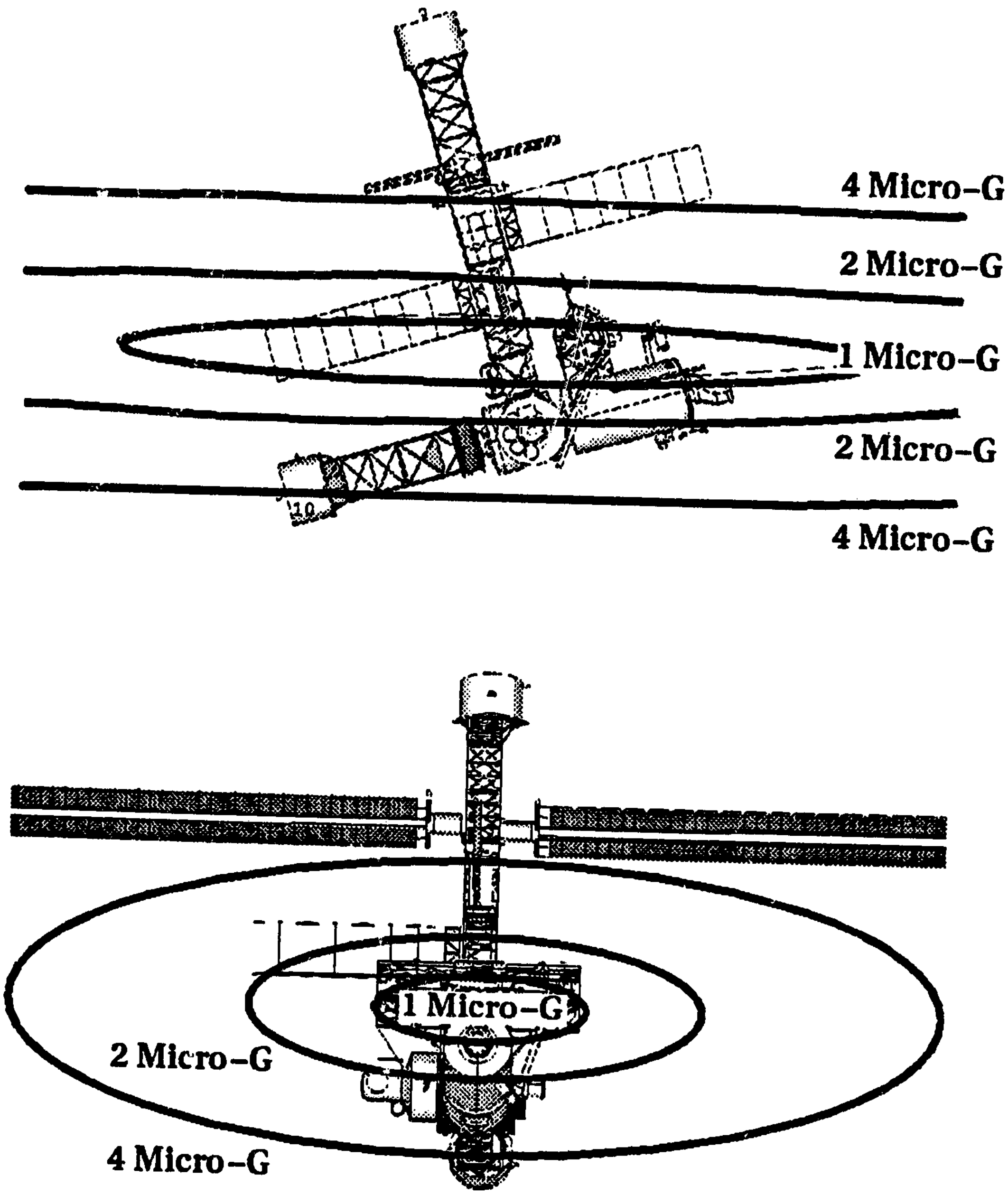


Figure 5.10.4-1 Stage 10 steady-state microgravity environment contours.

Table 5.10.4-2 summarizes the reboost lifetime characteristics of Stage 10 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 16.4 lbs/ft^2. The reboost was performed using the zenith bus, which currently has a reboost efficiency of 100%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement. This stage violates the 90 day decay to 150 n.mi. lifetime requirement.

Table 5.10.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
215	232	1,703	3,084	9,897	80

The control characteristics of Stage 10 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.10.4-2. No momentum wheel augmentation was utilized. Table 5.10.4-3 summarizes the control characteristics depicted in the plots.

Table 5.10.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	0.6 degrees	18.7 degrees	2.1 degrees	± 0.9 degrees	2300 N-m-s
w/STS	1.8 degrees	-26.6 degrees	-0.1 degrees	± 0.2 degrees	3000 N-m-s

The control characteristics of Stage 10 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.10.4-3. No momentum wheel augmentation was utilized. Table 5.10.4-3 summarizes the control characteristics depicted in the plots.

During Shuttle mated assembly flights, periodic attitude maneuvers will be required to avoid exceeding thermal loads on the Shuttle during certain solar geometry conditions. The maneuver must be able to be performed using the RCS thrusters from *either* bus starting from Stage 10.

Three sample mated configurations were selected for analysis : Stage 10, when the upper bus is delivered, Stage 17/Flight 12A, and Stage 36/Flight 1°A. The CDR RCS attitude maneuver control algorithm was employed. A 180 degree yaw maneuver was performed.

It should be noted that the total impulse per attitude control thruster is 134,000 lb_f-sec.

For Stage 10, a 0.1 degree/sec rate limit was utilized. The 180 degree yaw maneuver took approximately 1800 seconds (~1/3 orbit) for both the aft and zenith bus. There was about a 16 degree overshoot in the yaw channel, and about 7 degree overshoot in pitch. Approximately 20 lbs. of fuel were required for the upper bus; 16 lb. for the aft bus. By and large, all four thrusters were used approximately equally. Using a lower rate limit

could reduce the amount of overshoot at the expense of the time required to reach the desired attitude. Table 5.10.4-4 lists the fuel and total impulse requirements

Table 5.10.4-4 Yaw Maneuver Fuel and Impulse Requirements

Bus	Fuel Used (lb.) / Total Impulse (lb.-sec)				Total Fuel (lb.)
	Nozzle #3	Nozzle #4	Nozzle #5	Nozzle #6	
aft	3.9 / 1163	3.1 / 903	5.1 / 1495	4.2 / 1228	16.2
zenith	5.4 / 1600	5.0 / 1462	5.4 / 1599	4.5 / 1332	20.3

5.10.5 Issues and Concerns

This stage violates the 90 day to 150 n.mi. altitude lifetime requirement.

There is a possibility of some indirect plume impingement of the aft P6 radiator from the aft bus attitude control thrusters.

This stage has a pitch flight attitude that exceeds ±15 degrees (with and without an attached Shuttle).

A PDGF on the zenith side of the S0 segment will be required for installation of the zenith bus and extender truss

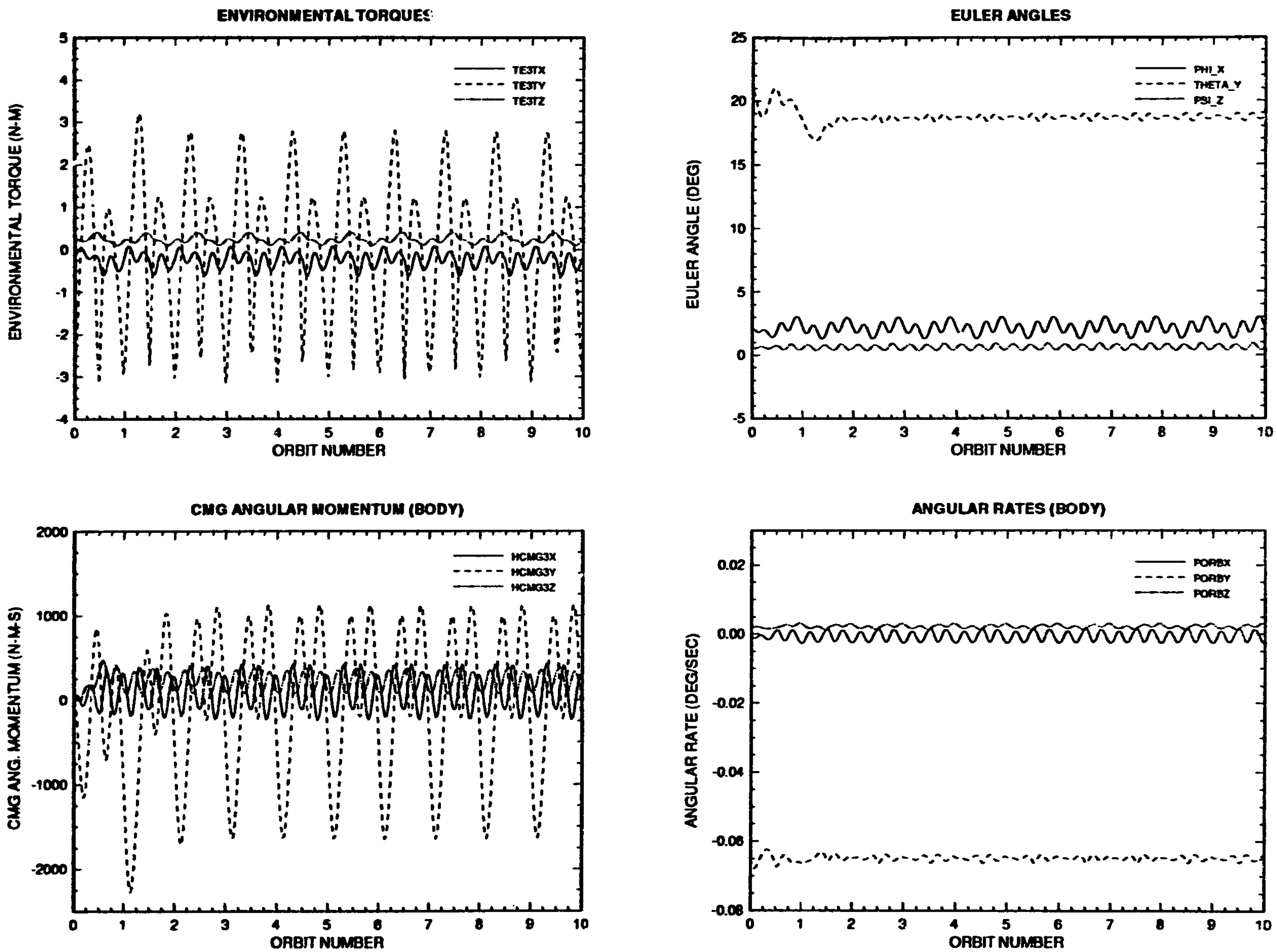


Figure 5.10.4-2 Stage 10 control plots without Shuttle attached.

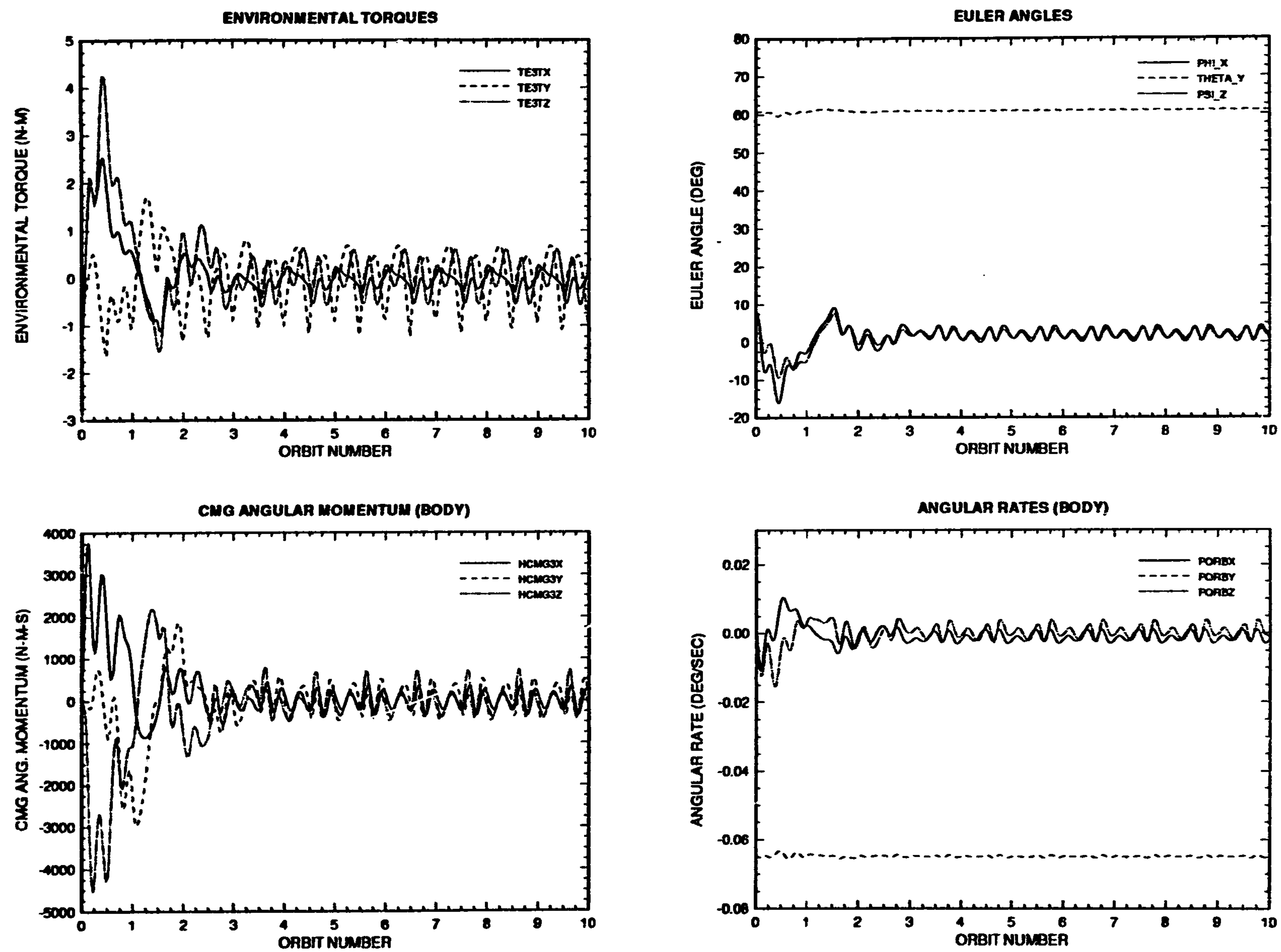


Figure 5.10.4-3 Stage 10 control plots with Shuttle attached.

5.11 Stage 11 Flight Characterization

5.11.1 Stage 11 - Flight UF-2 Shuttle Flight Manifest

The Shuttle delivers the mobile base system (MBS) and the MPLM to exchange racks. Table 5.11.1-1 lists the Shuttle Flight Manifest for Stage 11 - Flight UF-2. The total mass of the station hardware to orbit is 5615 lbs (excluding the TBD racks which are exchanged) and FSE mass of 10705 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 25466 lbs to 215 n.mi. at an inclination of 51.6°. The flight mission margin is 9146 lbs, but does not include the TBD ISPR racks manifested in this flight.

5.11.2 Stage 11 Configuration

Figure 5.11.2-1 displays the isometric view of Stage 11 after the Shuttle departs and the scheduled assembly is completed. Figure 5.11.2-2 shows the front, side, top and isometric views of Stage 11 with the Shuttle attached.

5.11.3 Flight UF-2 Assembly Operations Description

Rendezvous of the Shuttle with the Stage 10 occurs along +V bar at an altitude of 215 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the forward Lab CBM in a tail down orientation.

Flight UF-2 is a 12 day mission with 1 EVA. The SSRMS attaches the Mobile Base Servicer (MBS) to the MT on S0 ITS. It is then deployed, activated, and checked out. The SSRMS removes the MPLM from the Shuttle payload bay and installs it on the Node 1 nadir port. After the racks are transferred and payload data samples are returned to the MPLM, it is returned to the Shuttle payload bay. Once the Node1 nadir port is clear, the SSRMS relocates PMA3 from the Node 1 port CBM to the Node 1 nadir port (Note: PMA3 will be the docking location during flight 10A).

Following separation, Stage 11 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 10 functionality, plus:

- MBS attached and activated
- PMA3 repositioned from Node 1 Port to Node 1 Nadir port (not operational)

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*12 crew-hours*	
Resources Required:	*Power:*	*8,679 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		409 W	*(CSA)*
	Thermal:	*TBD W*	
	EVA:	*9:30 crew-hours*	

Table 5.11.1-1 Stage 11 - Flight UF-2 Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
MPLM - 2		10705
Node 1 Stowage Rack 3	899	
JEM ELM-PS/US Stowage Rack 3	1188	
ISPR racks (exchanged)	TBD	
MBS	3528	
subtotal	**5615**	**10705**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		500
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-2314
APCU-I	714	
ROFU	450	
Misc. hardware	160	
Additional Attach Hardware	990	
	2314	
Variable Shuttle Consumables		-3161
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	330	
5th & 6th N2 tanks (@128 lbs/N2)	256	
5th Cryo Tank & Fluid	1575	
	3161	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1180
Maintenance Reserve		-530
Total Shuttle Lift Capability		**25466**

Mission Flight Margin		**9146**

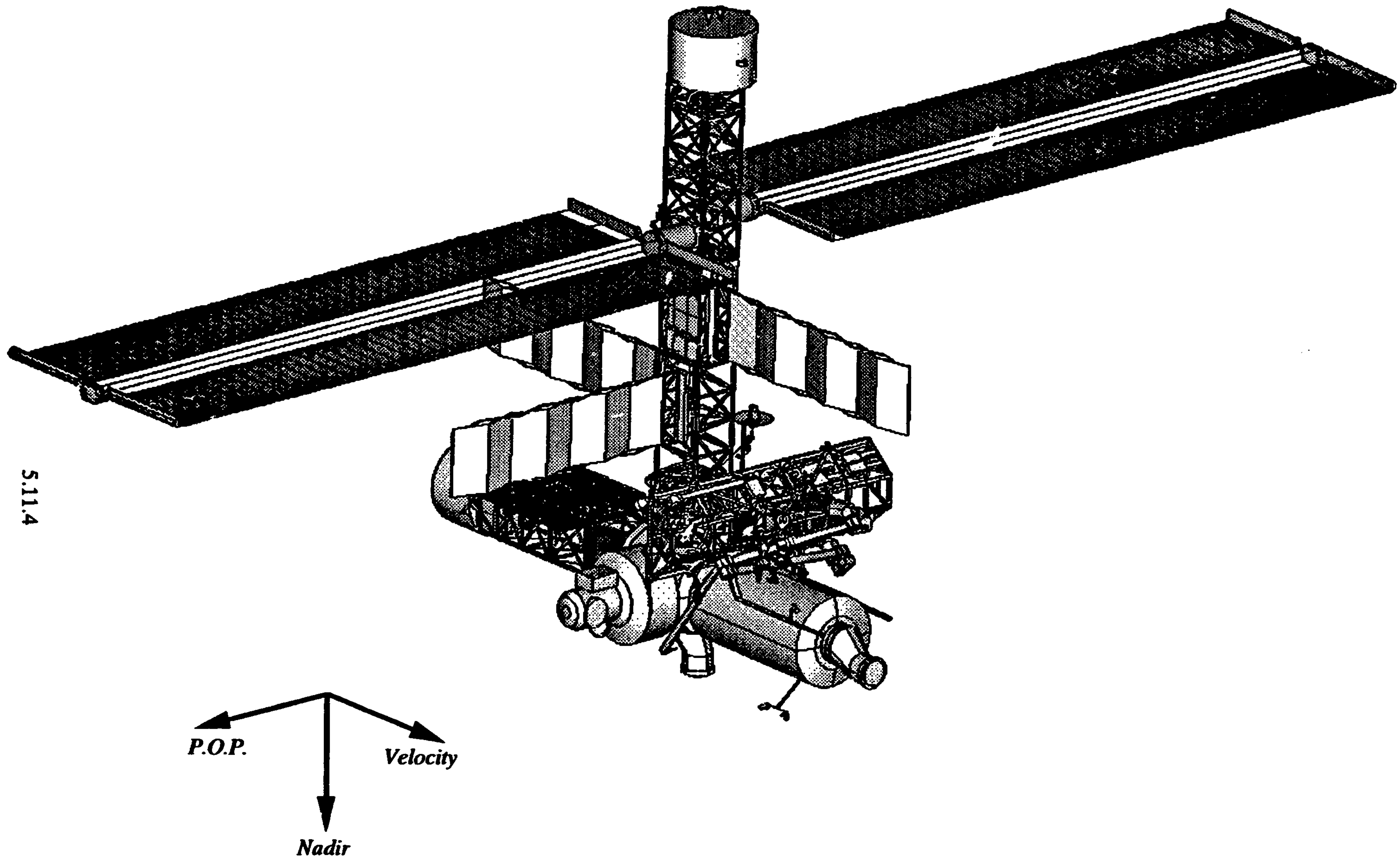


Figure 5.11.2-1 Stage 11 Configuration

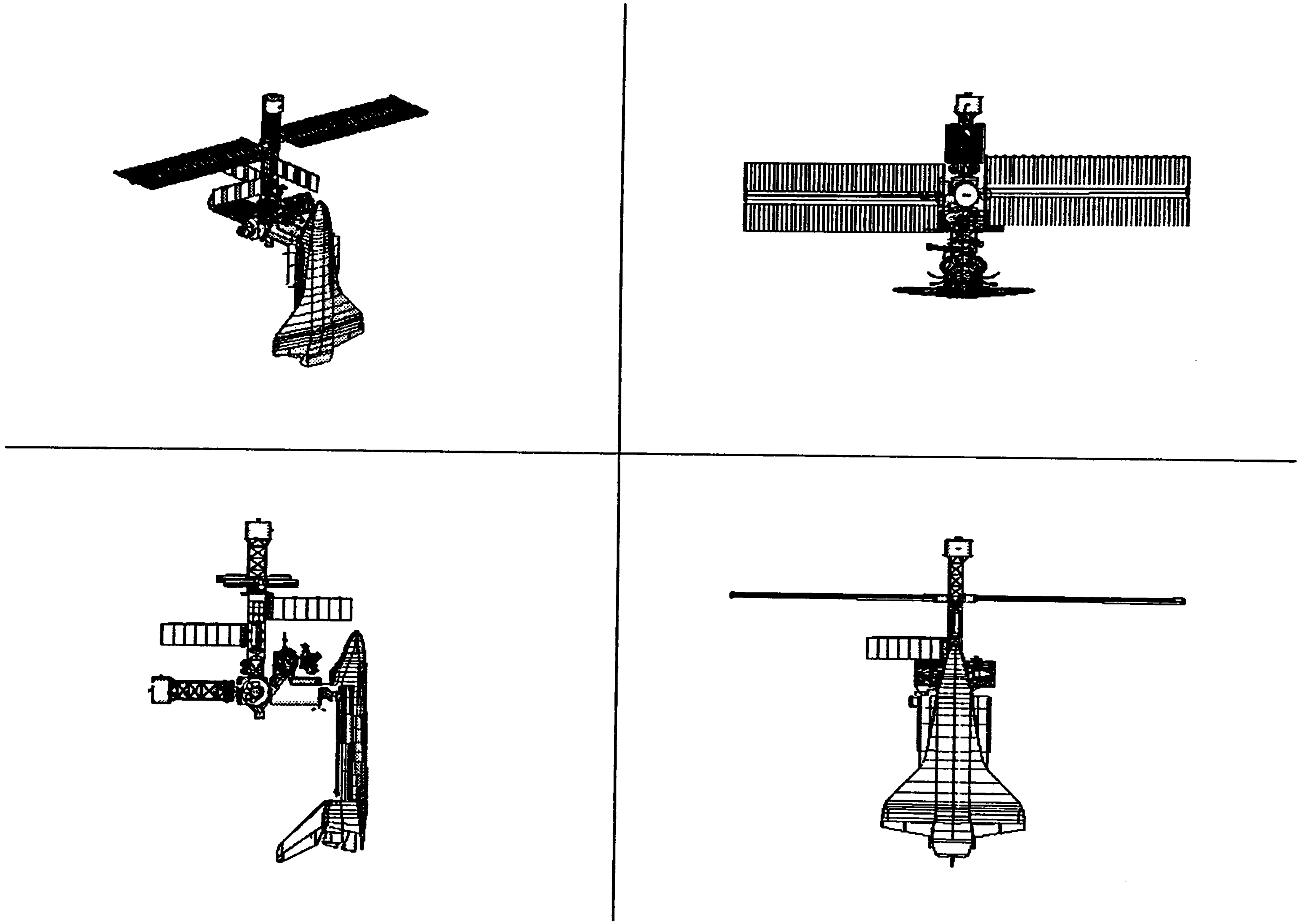


Figure 5.11.2-2 Stage 11 Configuration with Shuttle

5.11.4 Stage 11, Flight UF-2 Performance Characteristics

Stage 11, Flight UF-2 is assembled at a 215 n.mi. altitude in an LVLH flight mode with 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is October, 1999.

The Stage 11 steady state microgravity environment is depicted in figure 5.11.4-1. In a +2σ atmosphere (solar flux = 239.4, geomagnetic index = 18.7) this stage has a flight attitude of yaw = -1.3, pitch = 21.6, and roll = 2.1. Table 5.11.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 11 ISPR racks in the 1 μg environment.

Table 5.11.4-1 Stage 11 US Lab Racks Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	0.7
LAS-2	ISPR	0.9
LAS-3	ISPR	1.0
LAS-4	ISPR	1.2
LAS-5	SYS	1.4
LAS-6	SYS	1.5
LAF-1	SYS	1.2
LAF-2	SYS	1.4
LAF-3	SYS	1.5
LAF-4	SYS	1.7
LAF-5	SYS	1.9
LAF-6	SYS	2.1
LAP-1	ISPR	0.8
LAP-2	ISPR	0.9
LAP-3	ISPR	1.0
LAP-4	ISPR	1.2
LAP-5	SYS	1.4
LAP-6	SYS	1.5
LAC-1	ISPR	0.5
LAC-2	ISPR	0.5
LAC-3	ISPR	0.6
LAC-4	ISPR	0.7
LAC-5	ISPR	0.9
LAC-6	SYS	1.0

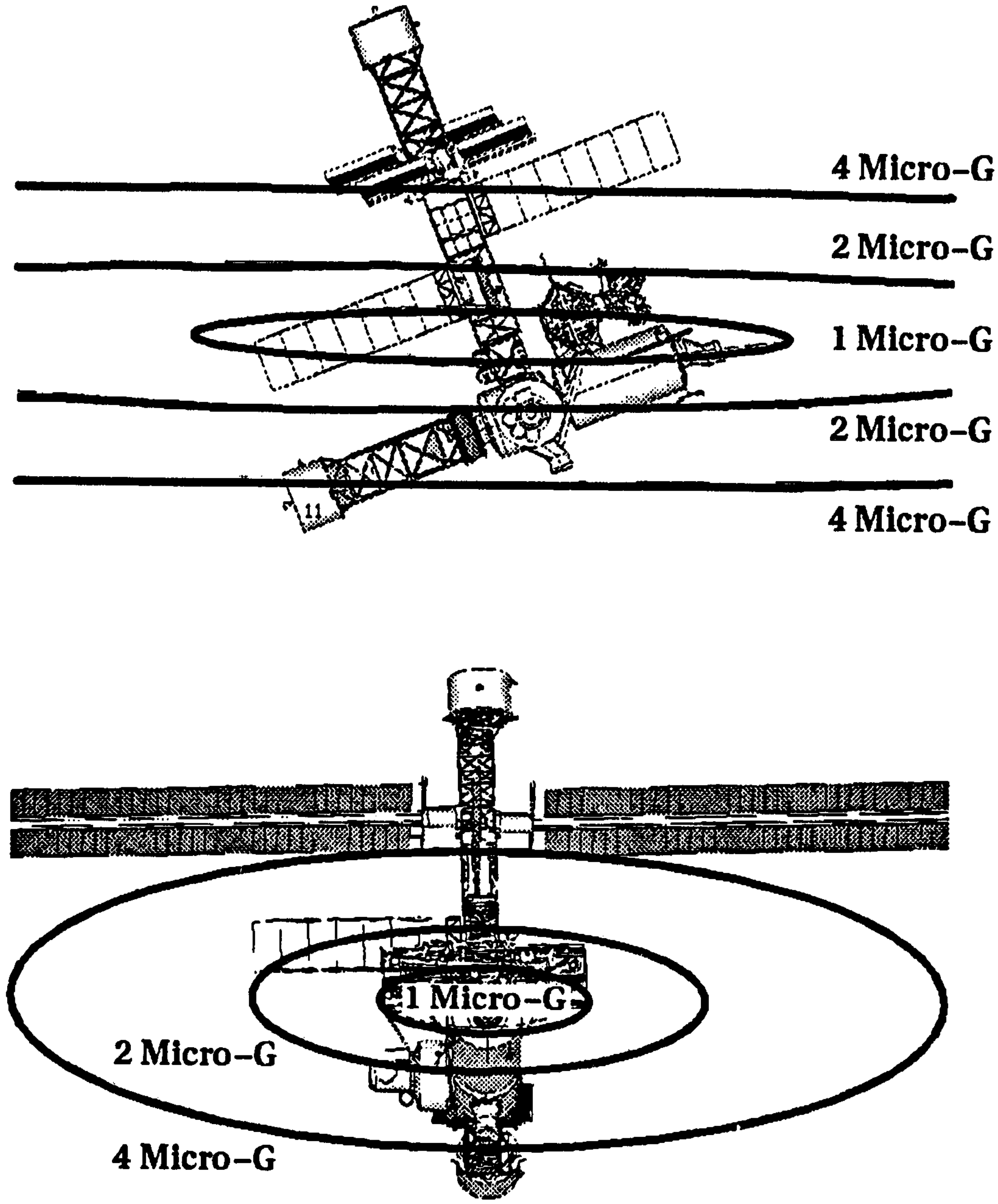


Figure 5.11.4-1 Stage 11 steady-state microgravity environment contours.

Table 5.11.4-2 summarizes the reboost lifetime characteristics of Stage 11 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 16.6 lbs/ft^2. The reboost was performed using the zenith bus, which has a reboost efficiency of 100%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement. This stage violates the 90 day decay to 150 n.mi. lifetime requirement.

Table 5.11.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
215	232	1,719	3,084	8,178	85

The control characteristics of Stage 11 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.11.4-2. No momentum wheel augmentation was utilized. Table 5.11.4-3 summarizes the control characteristics depicted in the plots.

Table 5.11.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	-1.3 degrees	24.8 degrees	2.1 degrees	± 1.4 degrees	2200 N-m-s
w/STS	0.0 degrees	-25.9 degrees	-0.2 degrees	± 0.2 degrees	4600 N-m-s

The control characteristics of Stage 11 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.11.4-3. No momentum wheel augmentation was utilized. Table 5.11.4-3 summarizes the control characteristics depicted in the plots.

5.11.5 Issues and Concerns

This stage violates the 90 day to 150 n.mi. altitude lifetime requirement.

This stage has a pitch flight attitude that exceeds ±15 degrees (with and without an attached shuttle).

There is a possibility of some indirect plume impingement of the aft P6 radiator from the aft bus attitude control thrusters.

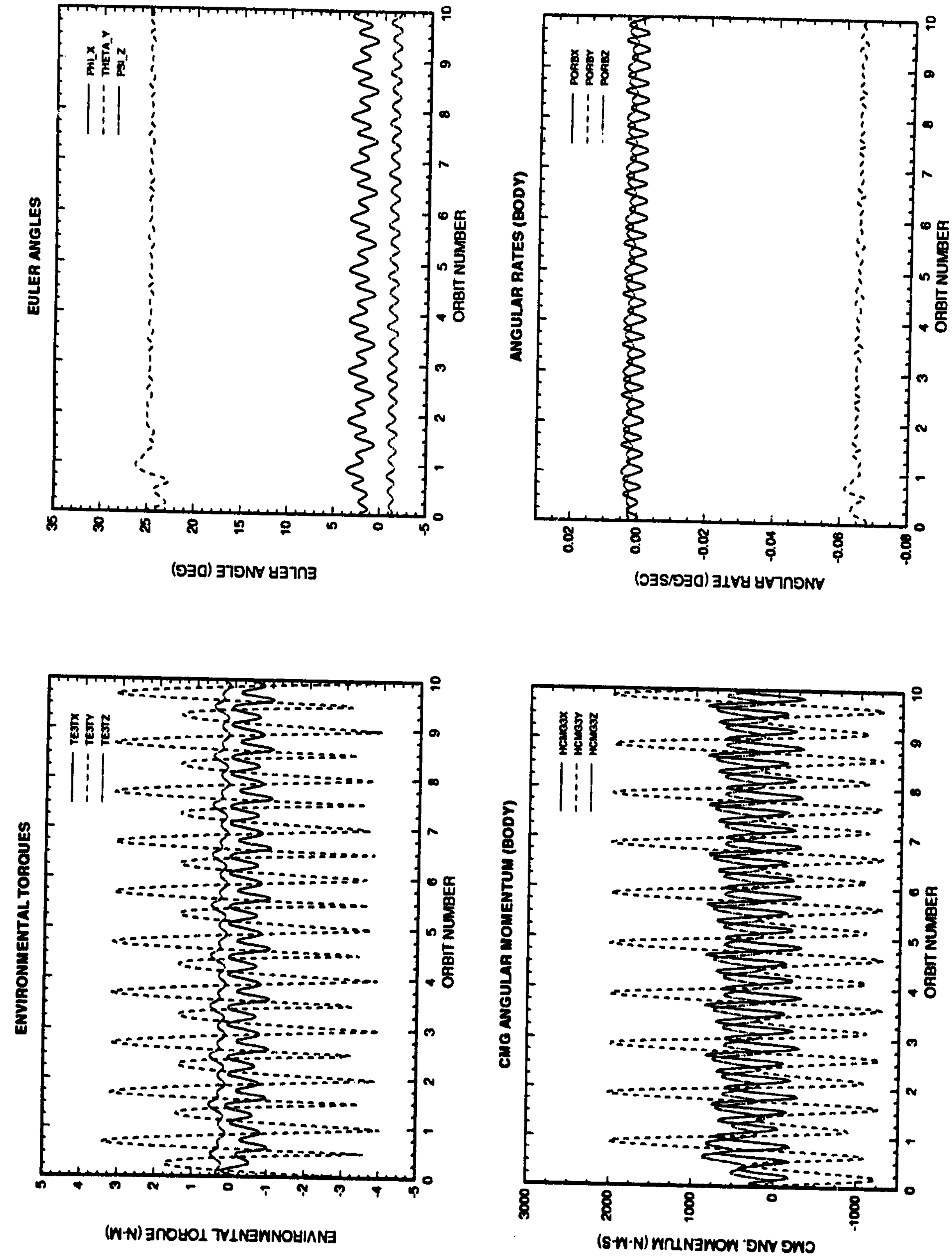


Figure 5.11.4-2 Stage 11 control plots without Shuttle attached.

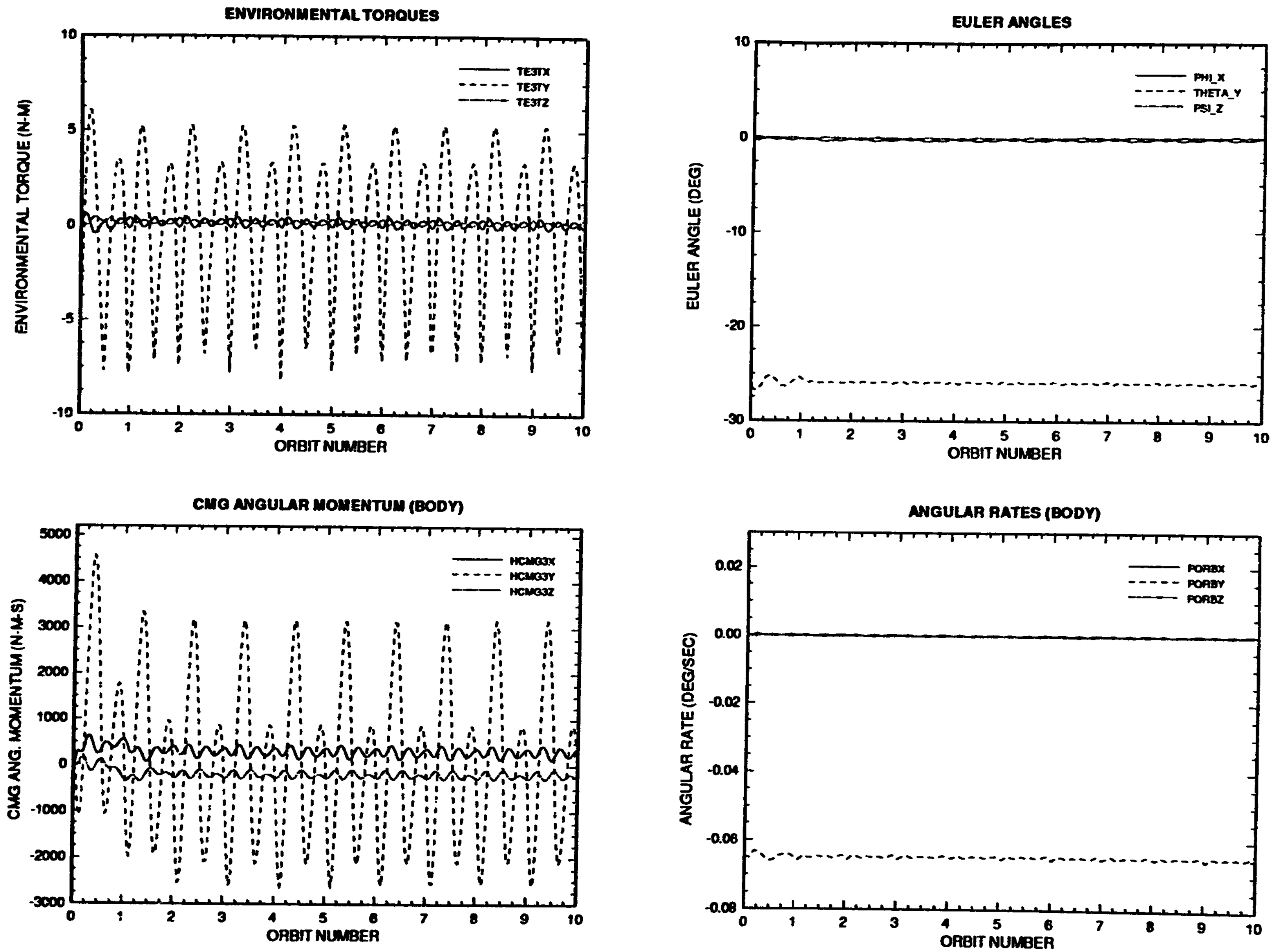


Figure 5.11.4-3 Stage 11 control plots with Shuttle attached.

5.12 Stage 12 Flight Characterization

5.12.1 Stage 12 - Flight 9A Shuttle Flight Manifest

The Shuttle delivers the S1 segment. Table 5.12.1-1 lists the Shuttle Flight Manifest for Stage 12 - Flight 9A. The total mass of the station hardware to orbit is 31026 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 30780 lbs to 215 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a small negative mission flight margin of -246 lbs.

5.12.2 Stage 12 Configuration

Figure 5.12.2-1 displays the isometric view of Stage 12 after the Shuttle departs and the scheduled assembly is completed. Figure 5.12.2-2 shows the front, side, top and isometric views of Stage 12 with the Shuttle attached.

5.12.3 Flight 9A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 11 occurs along +V bar at an altitude of 215 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the forward Lab CBM in a tail down orientation.

Assembly flight 9A is a 7 day mission with 2 EVAs. The SSRMS unberths the S1 ITS from the Shuttle payload bay and installs it on stbd side of the S0 ITS. During EVA operations, the second string S-band antenna is deployed and checked out, the S1 outboard nadir camera is installed, and the Node 1 camera is relocated to the Lab. The CETA cart is deployed, but not attached to the MT (task deferred until following flight). The final task of EVA2 is connection of the PMA3-to-Node1 umbilicals.

Following separation, Stage 12 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 11 functionality, plus:

- Addition of S1 Starboard Segment TCS (Prepared but not activated)
- Redundant S-Band Communications systems
- Increased video coverage
- Deployed starboard CETA cart (prepared but not activated)

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*24 crew-hours*	
Resources Required:	*Power:*	*10,128 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		711 W	*(CSA)*
	Thermal:	*TBD W*	
	EVA:	*23:20 crew-hours*	

Table 5.12.1-1 Stage 12 - Flight 9A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
S1 TRUSS SEGMENT	9041	
S1 UTILITY TRAYS	4410	
S1 AVIONICS	911	
S1 DDCU	388	
NH3 TANK	1976	
TRRJ	1194	
THERMAL SHROUDS	235	
LAUNCH LOCKS	589	
S-BAND ANTENNA	277	
EVA CAMERAS	196	
NITROGEN TANK	647	
PUMP MODULE ASSY	778	
TCS Radiator Structure and Panels (3)	9702	
CETA Cart - A	682	
subtotal	**31026**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		500
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-238
Misc hardware	238	
	238	
Variable Shuttle Consumables		-183
Food & Gear (-55 lbs/day over 6)	55	
5th N2 tanks (@128 lbs/N2)	128	
	183	
Middeck Lockers		-210
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-400
Total Shuttle Lift Capability		**30780**
Mission Flight Margin		**-246**

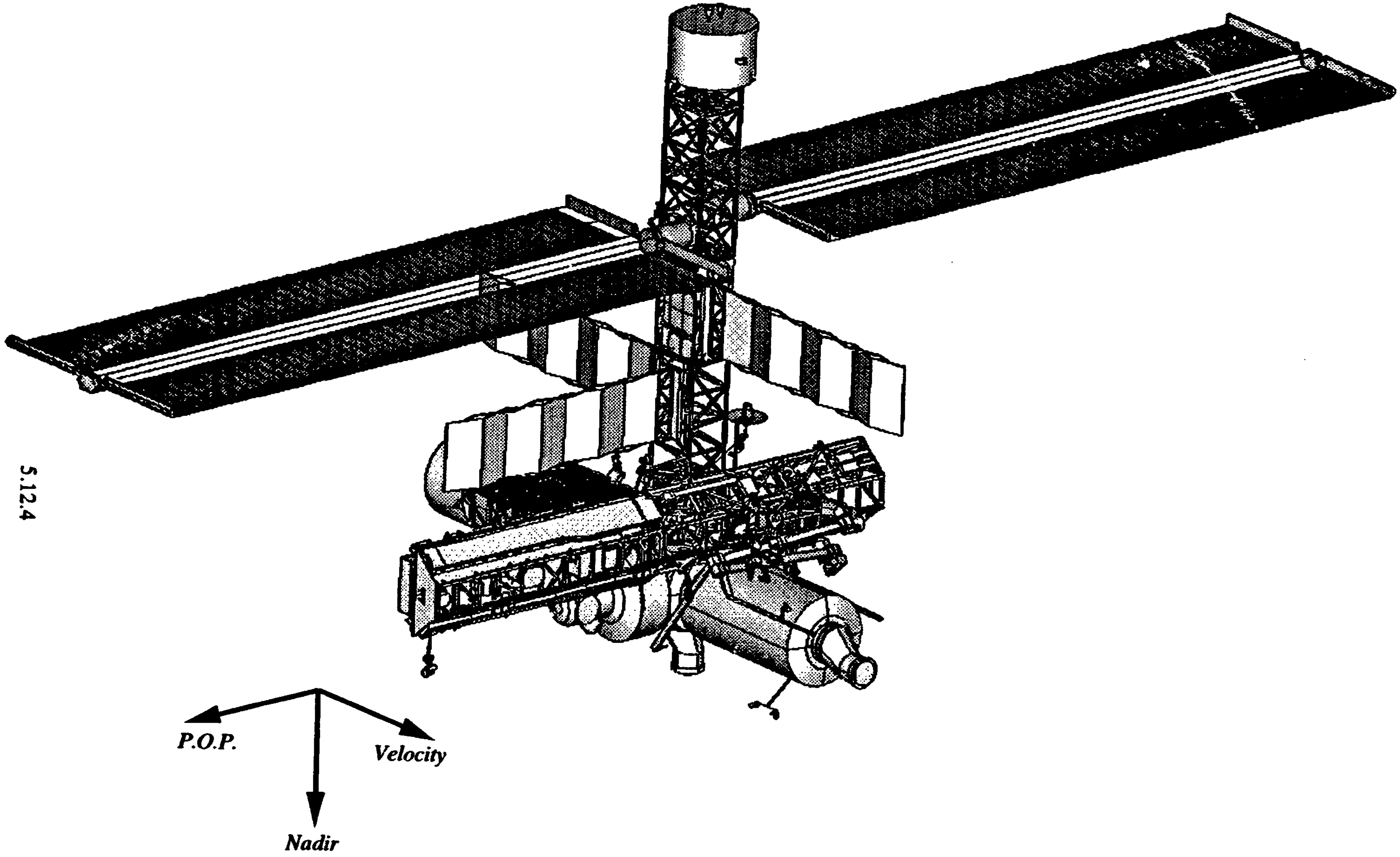


Figure 5.12.2-1 Stage 12 Configuration

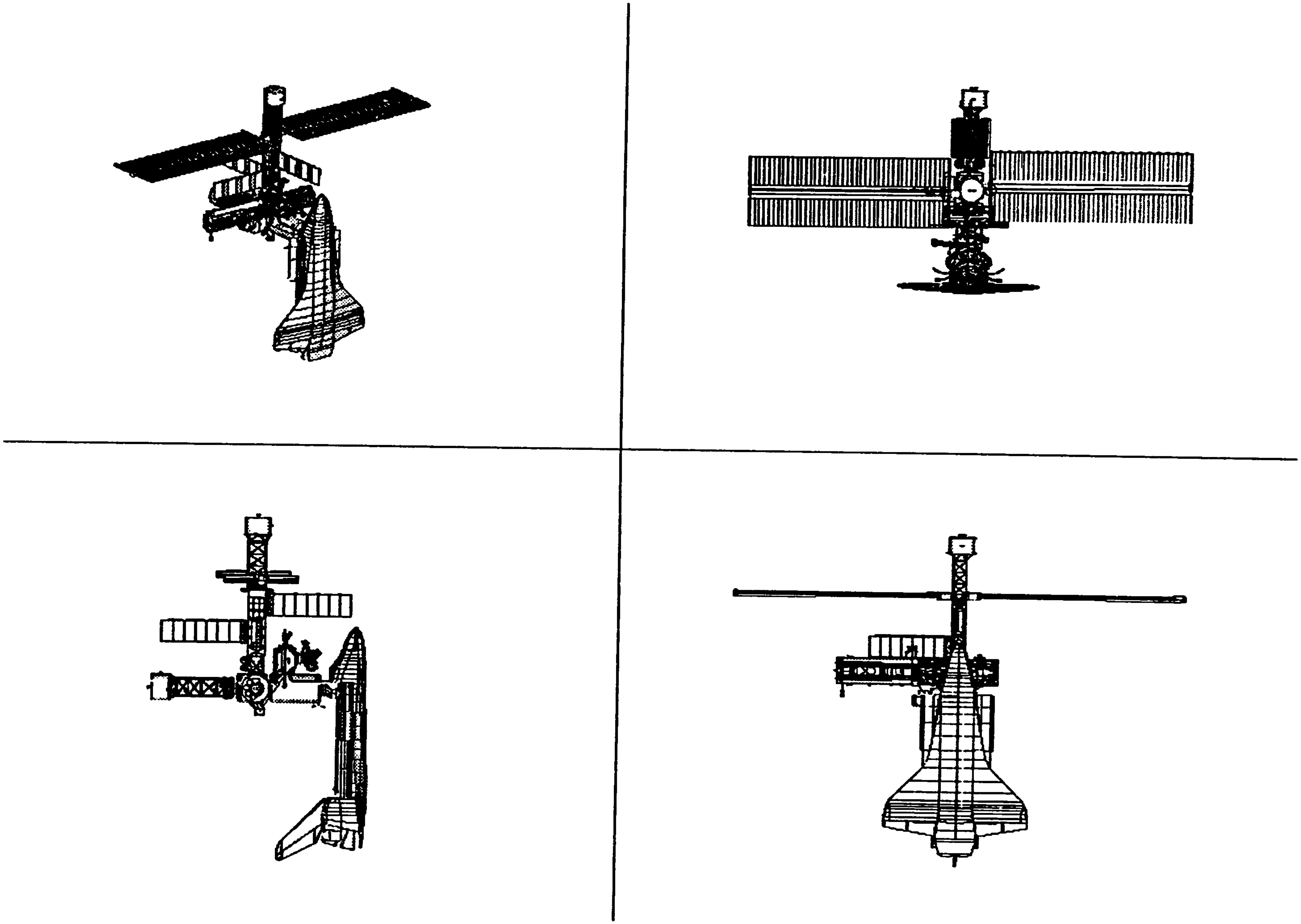


Figure 5.12.2–2 Stage 12 Configuration with Shuttle

5.12.4 Stage 12, Flight 9A Performance Characteristics

Stage 12, Flight 9A is assembled at a 215 n.mi. altitude in an LVLH flight mode with 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is December, 1999.

The Stage 12 steady state microgravity environment is depicted in figure 5.12.4-1. In a $+2\sigma$ atmosphere (solar flux = 232.9, geomagnetic index = 19.6) this stage has a flight attitude of yaw = 0, pitch = 19.7, and roll = 3.1. Table 5.12.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given $+2\sigma$ atmosphere. This configuration contains 6 ISPR racks in the 1 μg environment.

Table 5.12.4-1 Stage 12 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.0
LAS-2	ISPR	1.1
LAS-3	ISPR	1.3
LAS-4	ISPR	1.4
LAS-5	SYS	1.6
LAS-6	SYS	1.7
LAF-1	SYS	1.5
LAF-2	SYS	1.6
LAF-3	SYS	1.8
LAF-4	SYS	2.0
LAF-5	SYS	2.1
LAF-6	SYS	2.3
LAP-1	ISPR	1.0
LAP-2	ISPR	1.2
LAP-3	ISPR	1.3
LAP-4	ISPR	1.4
LAP-5	SYS	1.6
LAP-6	SYS	1.7
LAC-1	ISPR	0.6
LAC-2	ISPR	0.7
LAC-3	ISPR	0.8
LAC-4	ISPR	0.9
LAC-5	ISPR	1.1
LAC-6	SYS	1.2

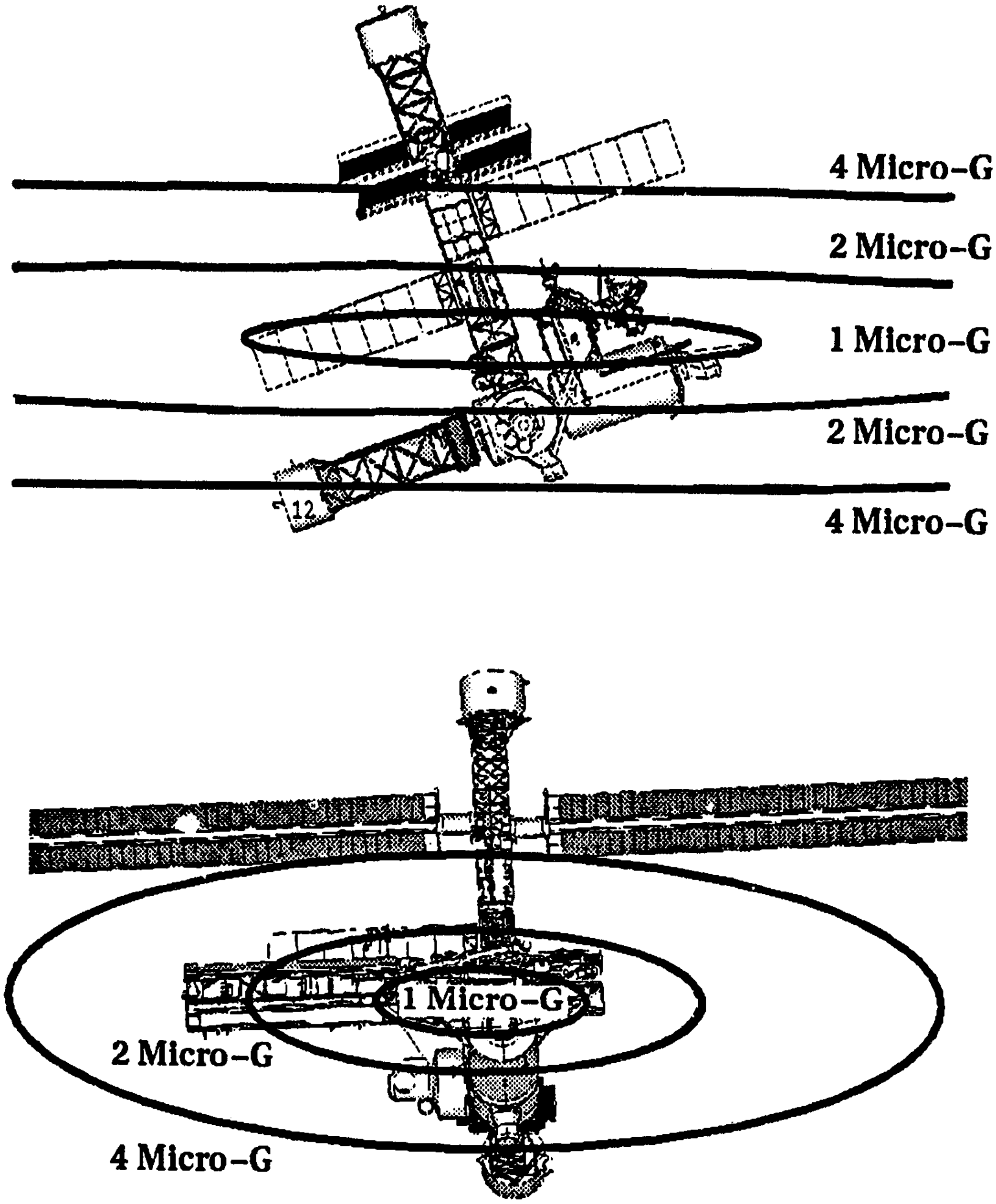


Figure 5.12.4-1 Stage 12 steady-state microgravity environment contours.

Table 5.12.4-2 summarizes the reboost lifetime characteristics of Stage 12 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 16.6 lbs/ft^2. The reboost was performed using the zenith bus, which has a reboost efficiency of 100%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.12.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
215	231	1,803	3,084	6,376	97

The control characteristics of Stage 12 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.12.4-2. No momentum wheel augmentation was utilized. Table 5.12.4-3 summarizes the control characteristics depicted in the plots.

Table 5.12.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	0.8 degrees	23.4 degrees	5.0 degrees	± 3.0 degrees	4000 N-m-s
w/STS	0.0 degrees	-25.7 degrees	-2.4 degrees	± 0.2 degrees	3200 N-m-s

The control characteristics of Stage 12 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.12.4-3. No momentum wheel augmentation was utilized. Table 5.12.4-3 summarizes the control characteristics depicted in the plots.

5.12.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees (with and without an attached Shuttle).

There is a small negative margin for the Shuttle manifest which will require weight reduction or utilization of reserve performance margins.

There is a possibility of some indirect plume impingement of the aft P6 radiator from the aft bus attitude control thrusters.

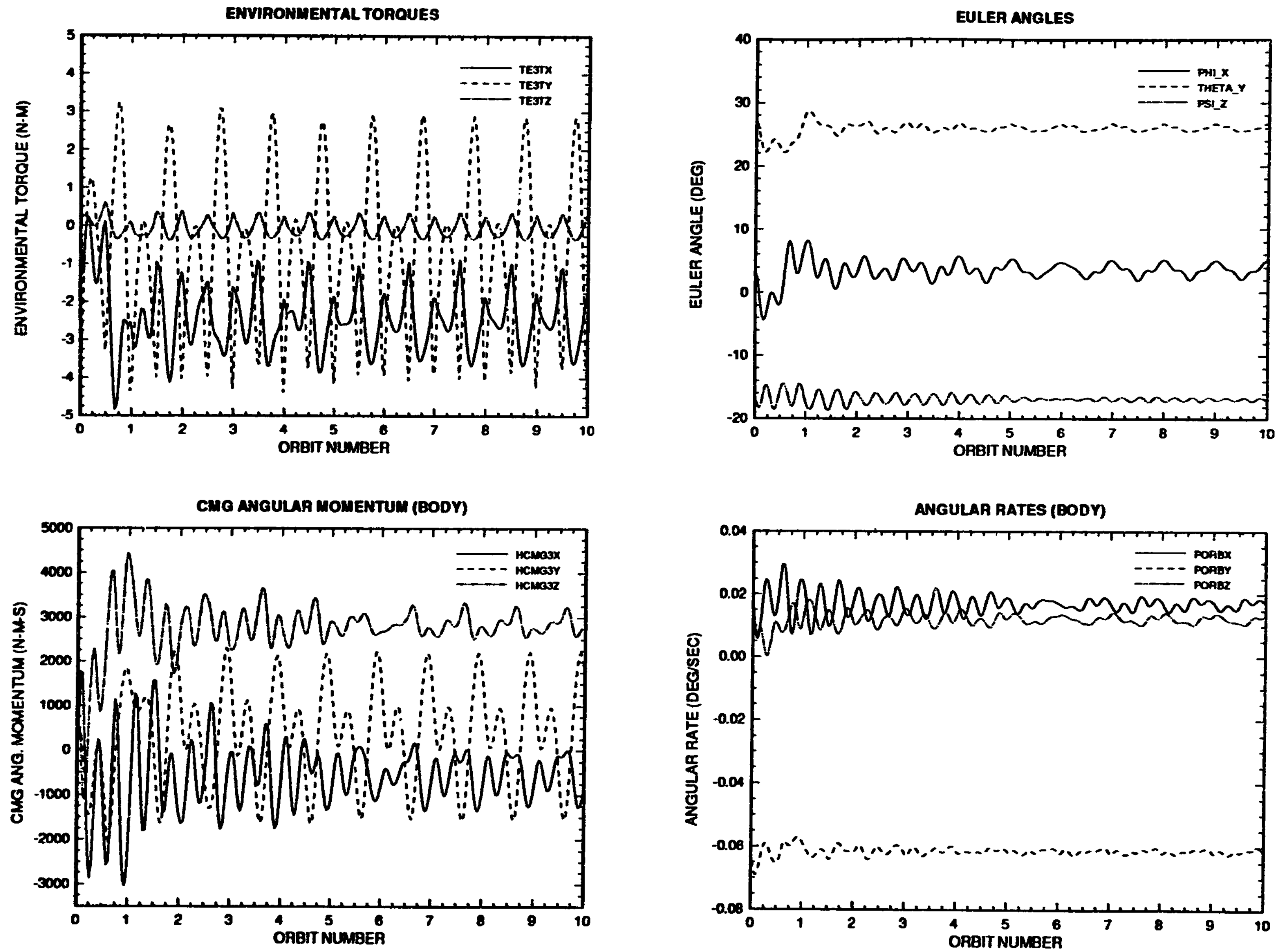


Figure 5.12.4-2 Stage 12 control plots without Shuttle attached.

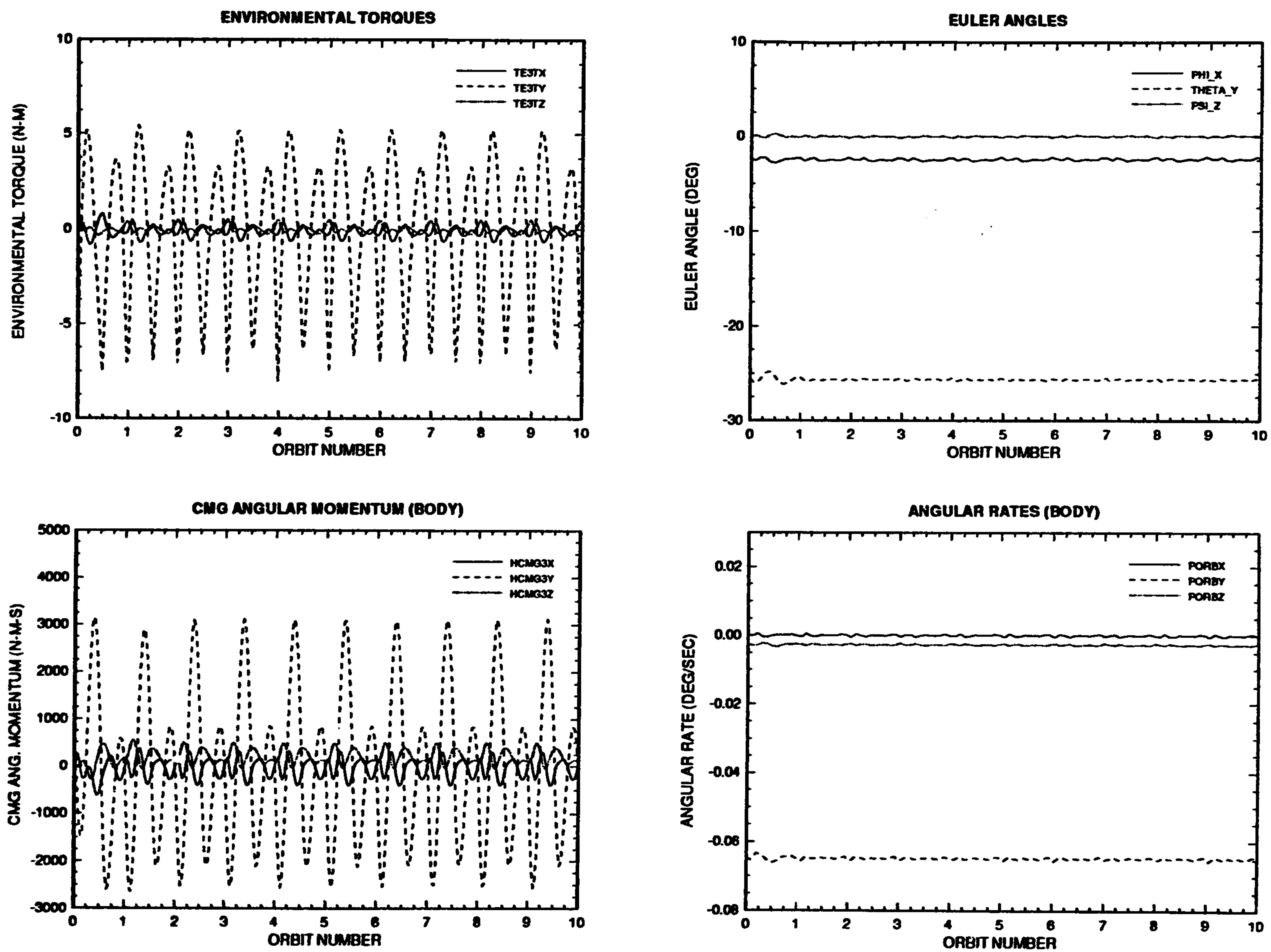


Figure 5.12.4-3 Stage 12 control plots with Shuttle attached.

5.13 Stage 13 Flight Characterization

5.13.1 Stage 13 - Flight 10A Shuttle Flight Manifest

The Shuttle delivers Node 2 and the cupola. Table 5.13.1-1 lists the Shuttle Flight Manifest for Stage 13 - Flight 10A. The total mass of the station hardware to orbit is 27359 lbs. The second section of the table shows the Shuttle Performance and hardware/ consumables required for the mission resulting in the net Shuttle Lift Capability of 28564 lbs to 215 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a mission flight margin of 1205 lbs.

5.13.2 Stage 13 Configuration

Figure 5.13.2-1 displays the isometric view of Stage 13 after the Shuttle departs and the scheduled assembly is completed. Figure 5.13.2-2 shows the front, side, top and isometric views of Stage 13 with the Shuttle attached.

5.13.3 Flight 10A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 12 occurs along +R bar at an altitude of 215 n.mi.. Station rendezvous attitude is -ZVV and +X Nadir. The Shuttle docks to PMA3 on the Node 1 nadir CBM in a tail port orientation.

Flight 10A is a 12 day mission with 4 EVAs. The first EVA completes the CETA cart installation and deployment, providing a fully functional CETA cart. The cupola arrives pre-integrated with Node 2 in the Shuttle payload bay. Following the disconnection of the PMA2-to-Lab umbilicals on EVA2, the SSRMS relocates PMA2 from the forward Lab port to the accessible radial Node 2 port still in the payload bay (see figure 5.13.3-1 for a graphical depiction of the operation). The combined Node 2/PMA2 element is then removed from the payload bay and installed on the Lab forward CBM (see figure 5.13.3-2 for graphical depiction of operation. Note: the action of the SSRMS entering the Shuttle cargo bay is done according to the JSC baseline document JSC-37960, section 4.10A, where the SSRMS enters the Shuttle cargo bay in order to grapple Node 2). Following completion of the IVA tasks necessary to prepare the cupola for relocation, the SSRMS grapples the cupola, detaches it from Node 2, and installs it on the port side of Node 1 (see figure 5.13.3-3 for a graphical depiction of the installation operations). The PMA2 is subsequently removed from the radial port and installed on the forward Node 2 CBM. During EVA operations, PMA2 and Node 2 umbilical trays and umbilicals are installed and connected.

Following separation, Stage 13 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 12 functionality, plus:

- Functional starboard CETA cart
- Active Node 2 (No ITCS or IP DDCUs)
- Tail down docking capability on Node 2
- IP module and Node 2 U.S. heat exchangers connected to ETCS

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*48 crew-hours*	
Resources Required:	*Power:*	*11,703 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		711 W	*(CSA)*
	Thermal:	*TBD W*	
	EVA:	*37:00 crew-hours*	

Table 5.13.1-1 Stage 13 - Flight 10A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
Node 2 - core	20983	
JEM DDCU Rack - 1	797	
JEM DDCU Rack - 2	860	
JEM DDCU Rack - 3	780	
JEM DDCU Rack - 4	852	
Cupola	3087	
subtotal	**27359**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		500
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		0
Variable Shuttle Consumables		-2417
Food & Gear (-55 lbs/day over 6)	330	
5th,6th, 7th & 8th N2 tanks (@128 lbs/N2)	512	
5th Cryo Tank & Fluid	1575	
	2417	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1270
Maintenance Reserve		-40
Total Shuttle Lift Capability		**28564**

Mission Flight Margin		**1205**

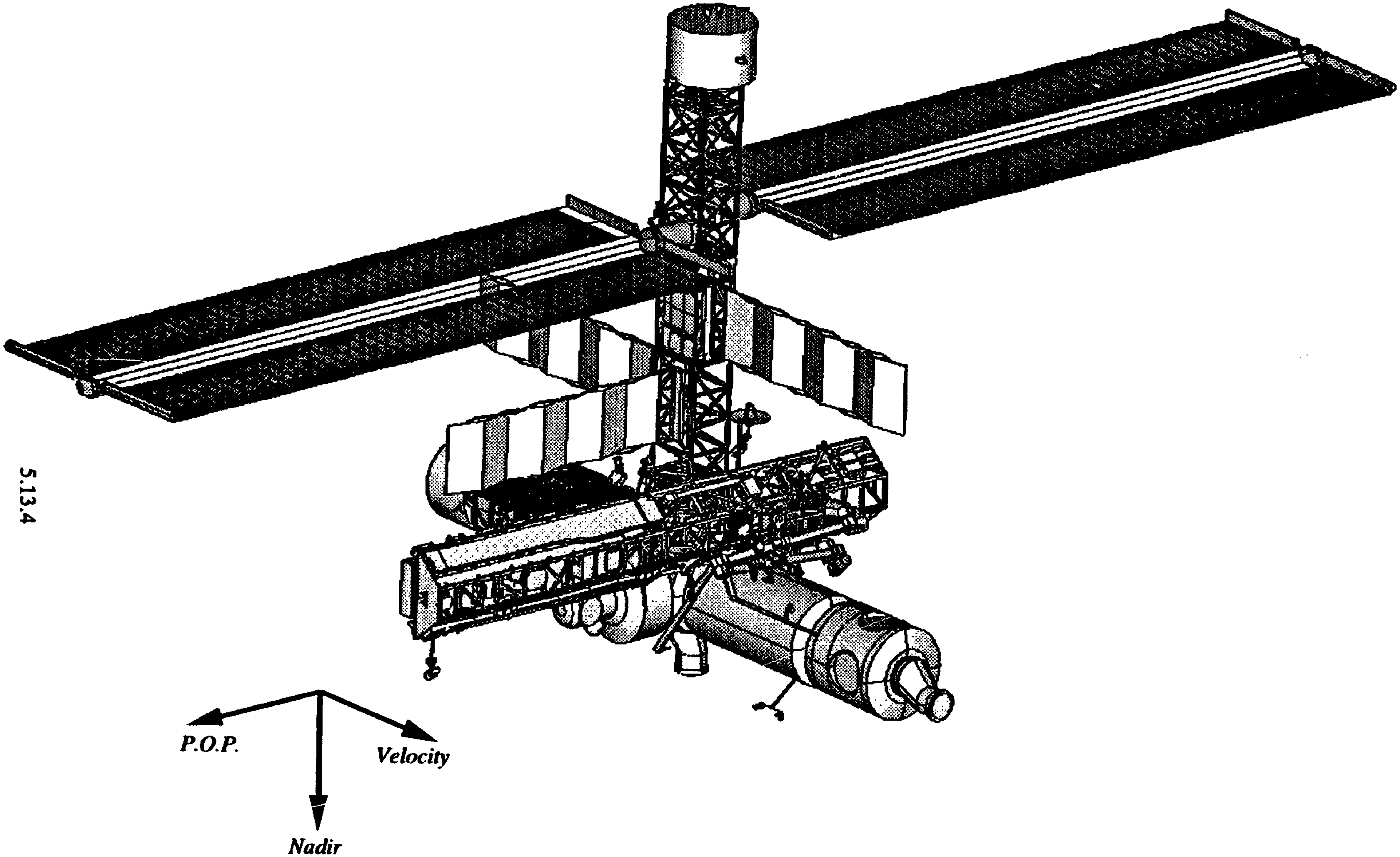


Figure 5.13.2–1 Stage 13 Configuration

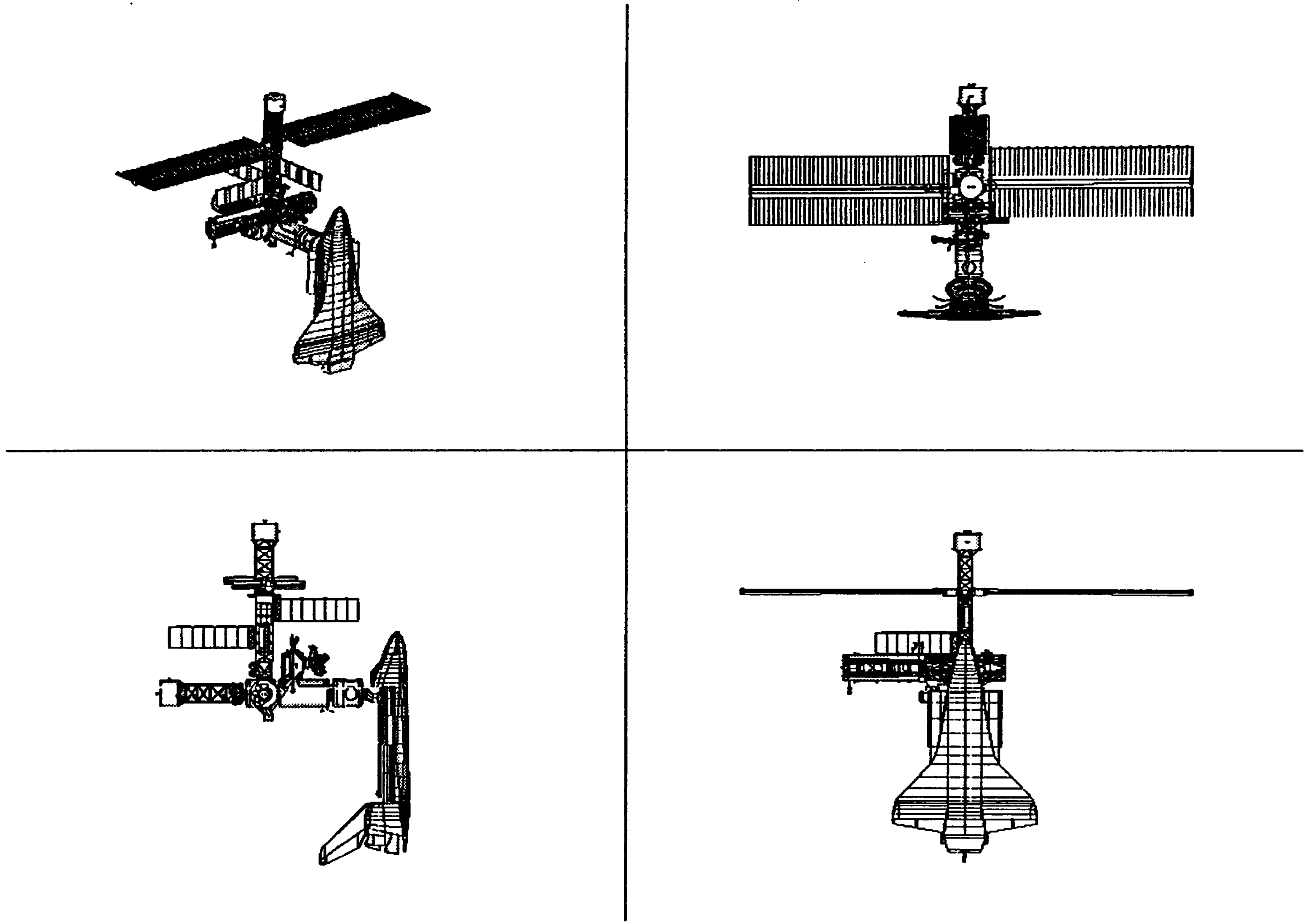


Figure 5.13.2-2 Stage 13 Configuration with Shuttle

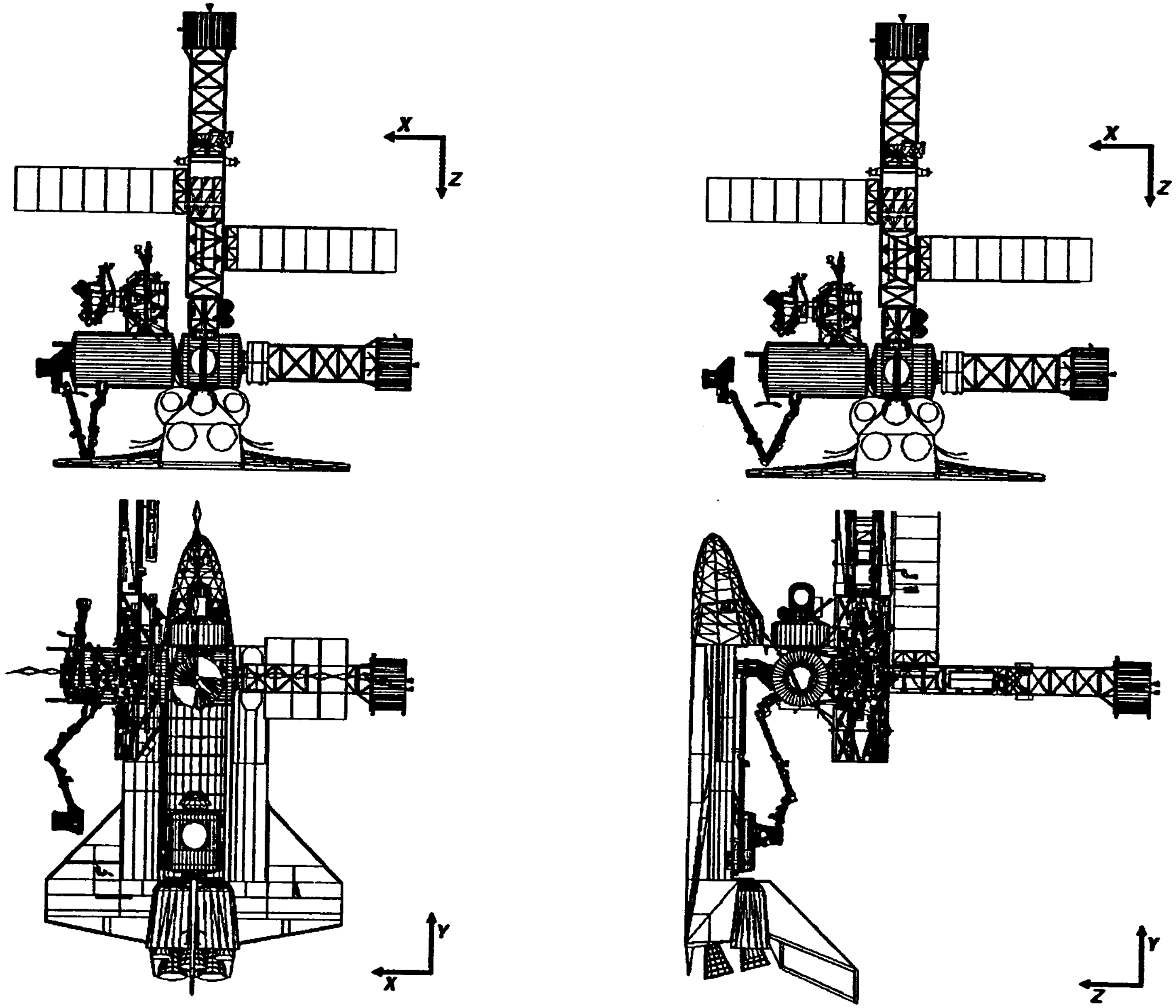


Figure 5.13.3-1 PMA 2 Relocation

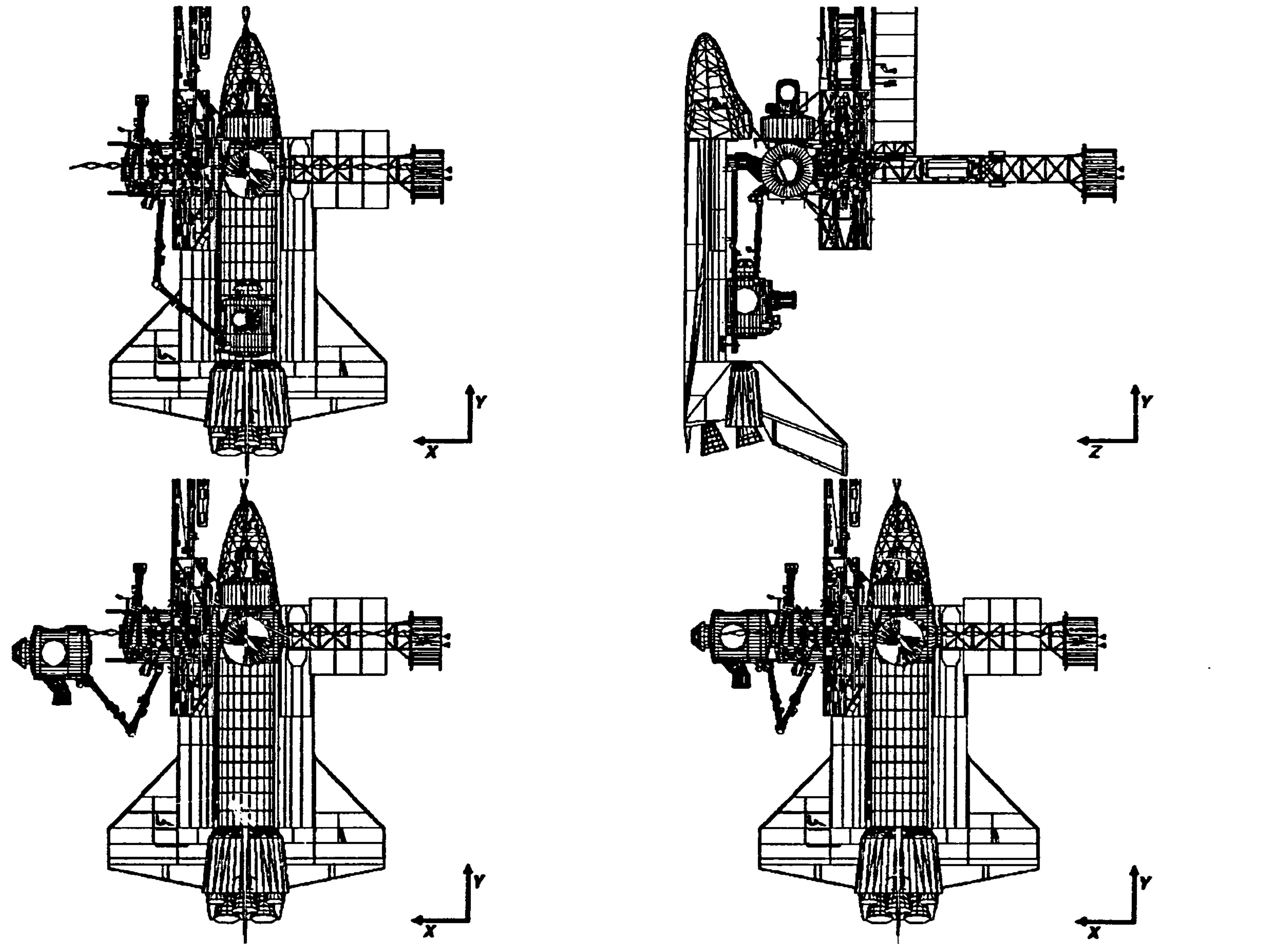


Figure 5.13.3–2 Node 2 Installation

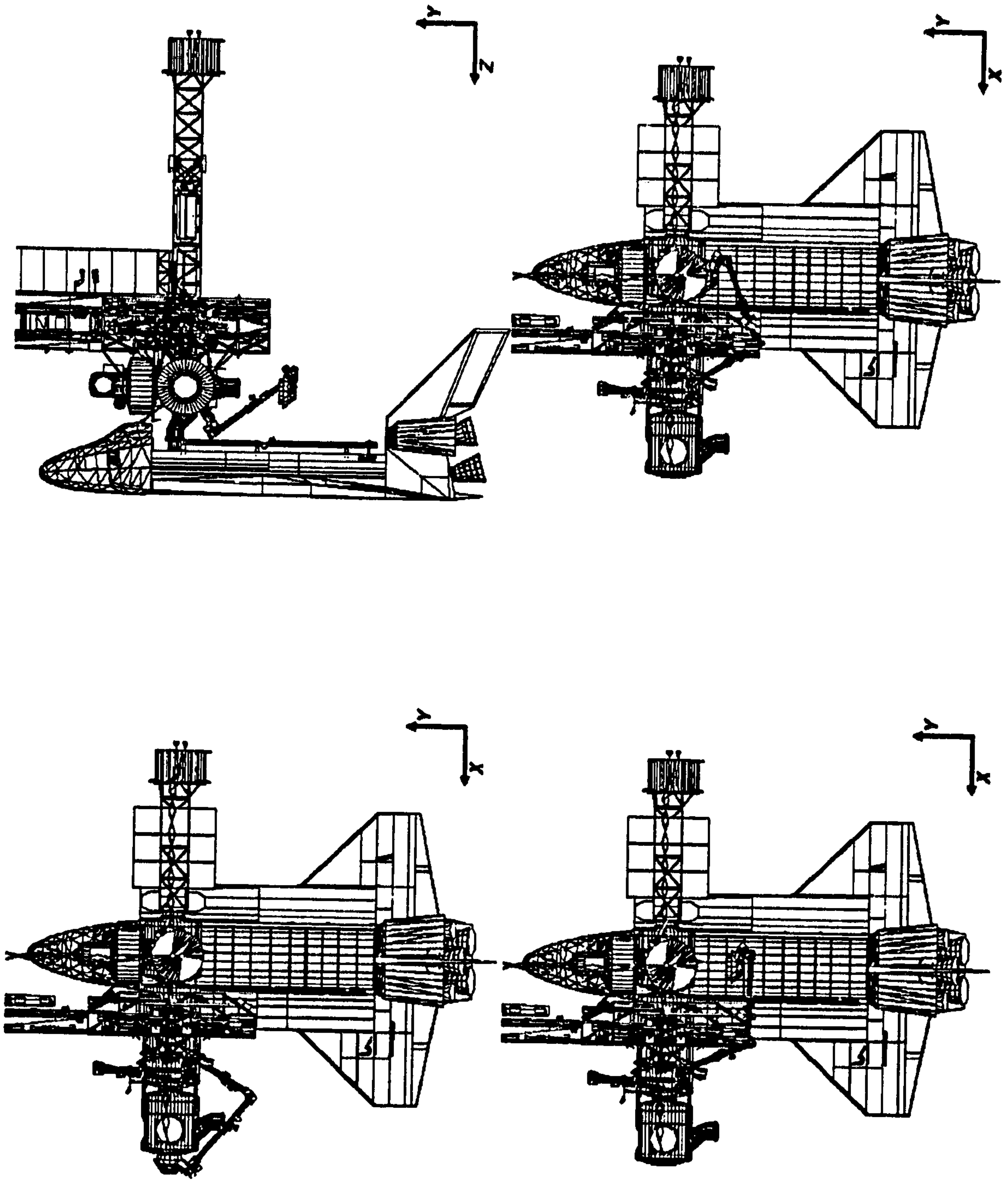


Figure 5.13.3-3 Cupola Installation

5.13.4 Stage 13, Flight 10A Performance Characteristics

Stage 13, Flight 10A is assembled at a 215 n.mi. altitude in an LVLH flight mode with 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is February, 2000.

The Stage 13 steady state microgravity environment is depicted in figure 5.13.4-1. In a $+2\sigma$ atmosphere (solar flux = 233.1, geomagnetic index = 21.0) this stage has a flight attitude of yaw = -6.5, pitch = 11.4, and roll = 1.2. Table 5.13.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2 sigma atmosphere. This configuration contains 4 ISPR racks in the 1 μg environment.

Table 5.13.4-1 Stage 13 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.3
LAS-2	ISPR	1.4
LAS-3	ISPR	1.5
LAS-4	ISPR	1.6
LAS-5	SYS	1.7
LAS-6	SYS	1.8
LAF-1	SYS	1.9
LAF-2	SYS	2.0
LAF-3	SYS	2.1
LAF-4	SYS	2.2
LAF-5	SYS	2.3
LAF-6	SYS	2.4
LAP-1	ISPR	1.4
LAP-2	ISPR	1.5
LAP-3	ISPR	1.5
LAP-4	ISPR	1.6
LAP-5	SYS	1.7
LAP-6	SYS	1.8
LAC-1	ISPR	0.8
LAC-2	ISPR	0.9
LAC-3	ISPR	0.9
LAC-4	ISPR	1.0
LAC-5	ISPR	1.1
LAC-6	SYS	1.2

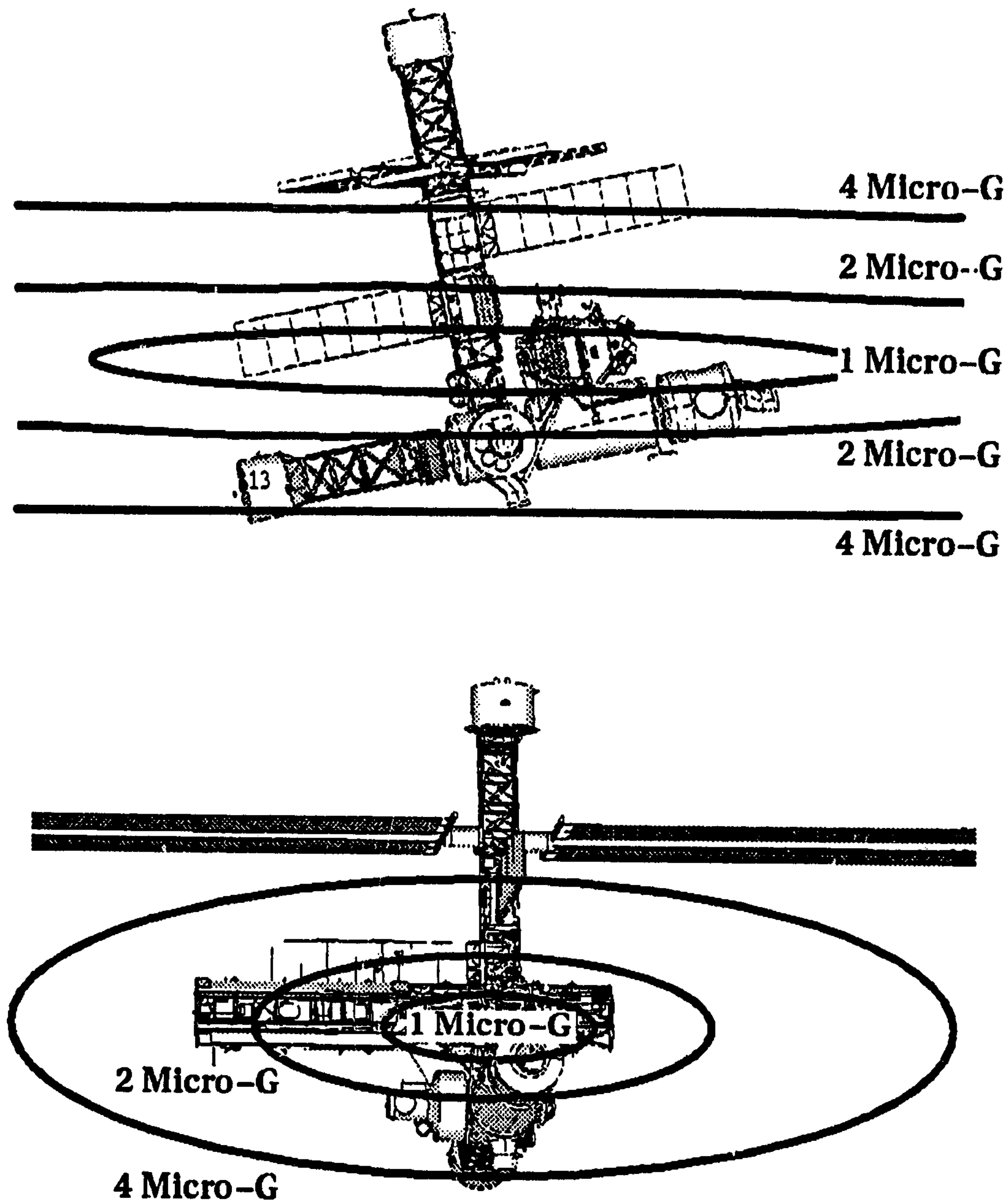


Figure 5.13.4-1 Stage 13 steady-state microgravity environment contours.

Table 5.13.4-2 summarizes the reboost lifetime characteristics of Stage 13 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 18.0 lbs/ft^2. The reboost was performed using the zenith bus, which has a reboost efficiency of 100%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.13.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
215	229	1,743	3,084	4,633	92

The control characteristics of Stage 13 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.13.4-2. The CMGs were augmented with a 5000 N-m-s momentum wheel. Table 5.13.4-3 summarizes the control characteristics depicted in the plots.

Table 5.13.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	-6.3 degrees	21.8 degrees	1.7 degrees	± 1.1 degrees	3200 N-m-s
w/STS	0.0 degrees	-36.9 degrees	-2.7 degrees	± 0.2 degrees	3500 N-m-s

The control characteristics of Stage 13 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.13.4-3. Table 5.13.4-3 summarizes the control characteristics depicted in the plots.

5.13.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees (with and without an attached Shuttle).

This stage requires a unique docking orientation for the Shuttle. Installation of Node 2 drives this docking orientation.

There is a possibility of some indirect plume impingement of the aft P6 radiator from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

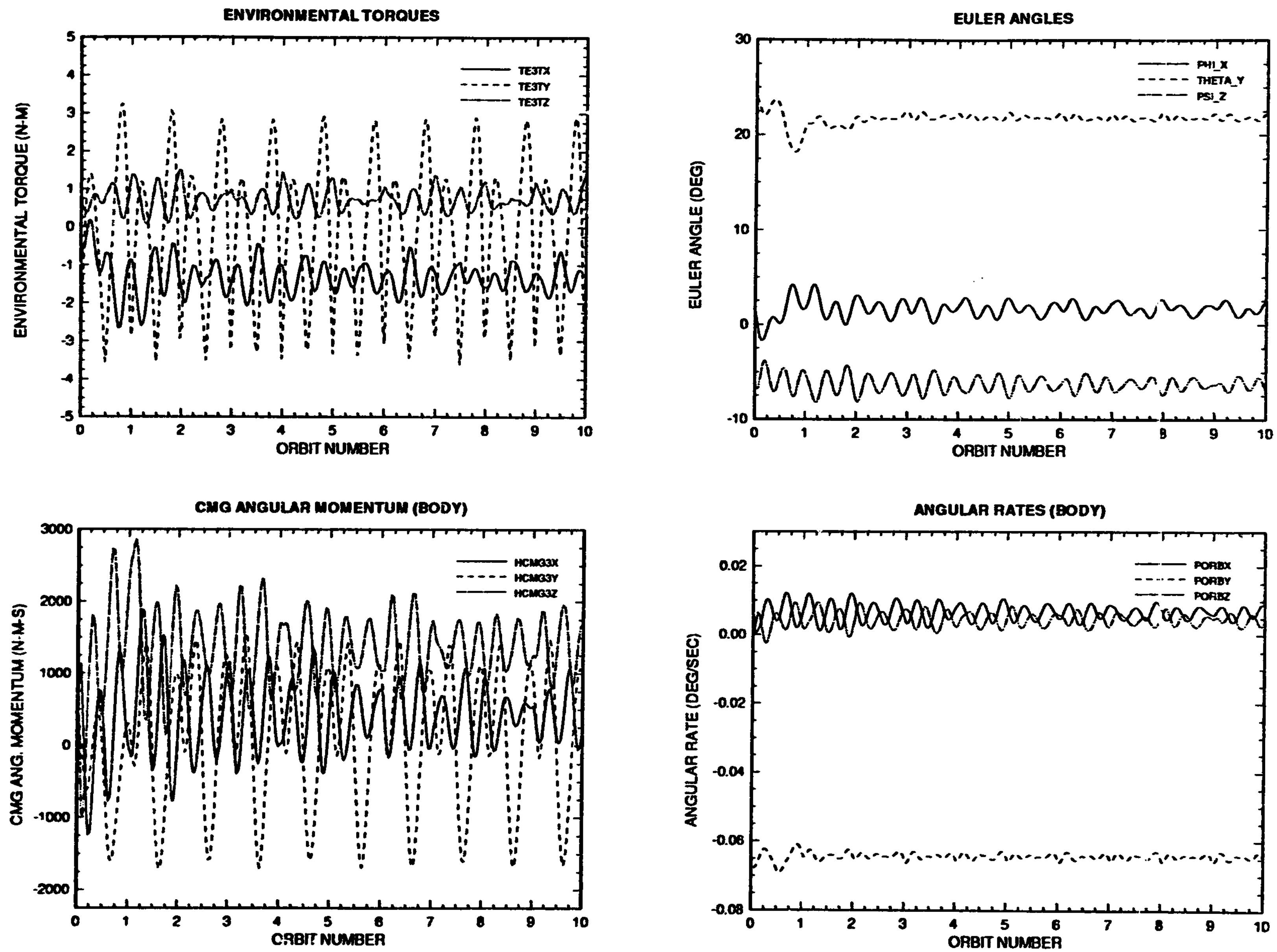


Figure 5.13.4-2 Stage 13 control plots without Shuttle attached.

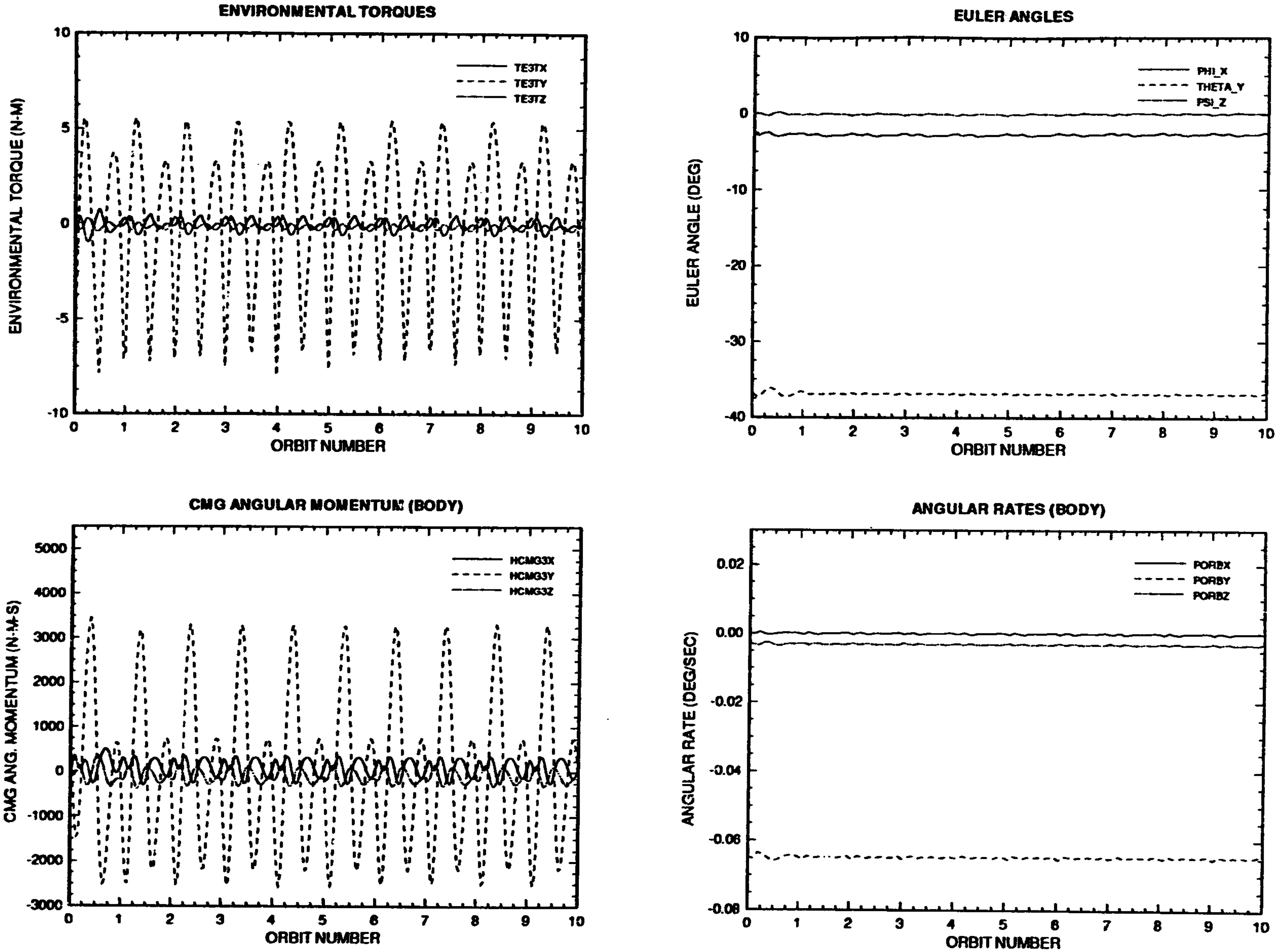


Figure 5.13.4-3 Stage 13 control plots with Shuttle attached.

5.14 Stage 14 Flight Characterization

5.14.1 Stage 14 - Flight 11A Shuttle Flight Manifest

The Shuttle delivers the P1 segment with the port TCS radiators. Table 5.14.1-1 lists the Shuttle Flight Manifest for Stage 14 - Flight 11A. The total mass of the station hardware to orbit is 30720 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 30414 lbs to 215 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a small negative mission flight margin of -306 lbs.

5.14.2 Stage 14 Configuration

Figure 5.14.2-1 displays the isometric view of Stage 14 after the Shuttle departs and the scheduled assembly is completed. Figure 5.14.2-2 shows the front, side, top and isometric views of Stage 14 with the Shuttle attached.

5.14.3 Flight 11A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 13 occurs along +V bar at an altitude of 215 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Assembly Flight 11A is a 9 day mission with 3 EVAs. The SRMS unberths the P1 ITS and hands-off the element to the SSRMS for installation on the S0 ITS port side. During EVA operations, the truss utility connections are made, the UHF antenna is deployed and activated, and external cameras are installed. The central TCS radiators on P1 and S1 are deployed. During the final EVA, CETA cart B is connected to the MT, providing the second functional CETA cart on-orbit. Relocation of the S-band RF group on P6 is delayed for two flights.

Following separation, Stage 14 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 13 functionality, plus:

- Port TCS added (prepared but not activated)
- Port external cameras

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*36 crew-hours*	
Resources Required:	*Power:*	*12,232 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		711 W	*(CSA)*
	Thermal:	*TBD W*	
	EVA:	*28:40 crew-hours*	

Table 5.14.1-1 Stage 14 - Flight 11A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
P1 TRUSS SEGMENT	8820	
P1 UTILITY TRAYS	4410	
P1 AVIONICS	911	
P1 DDCU	388	
UHF ANTENNA	119	
NH3 TANK	1976	
TRRJ	1194	
THERMAL SHROUDS	235	
LAUNCH LOCKS	589	
EVA CAMERAS	196	
NITROGEN TANK	647	
PUMP MODULE ASSY	778	
P1 LIGHT STANCION	72	
TCS Radiator Structure and Panels (3)	9702	
Ceta Cart - B	682	
subtotal	**30720**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		500
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-238
Variable Shuttle Consumables		-549
Food & Gear (-55 lbs/day over 6)	165	
5th, 6th & 7th N2 tanks (@128 lbs/N2)	384	
	549	
Middeck Lockers		-210
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-400
Total Shuttle Lift Capability		**30414**

Mission Flight Margin		**-306**

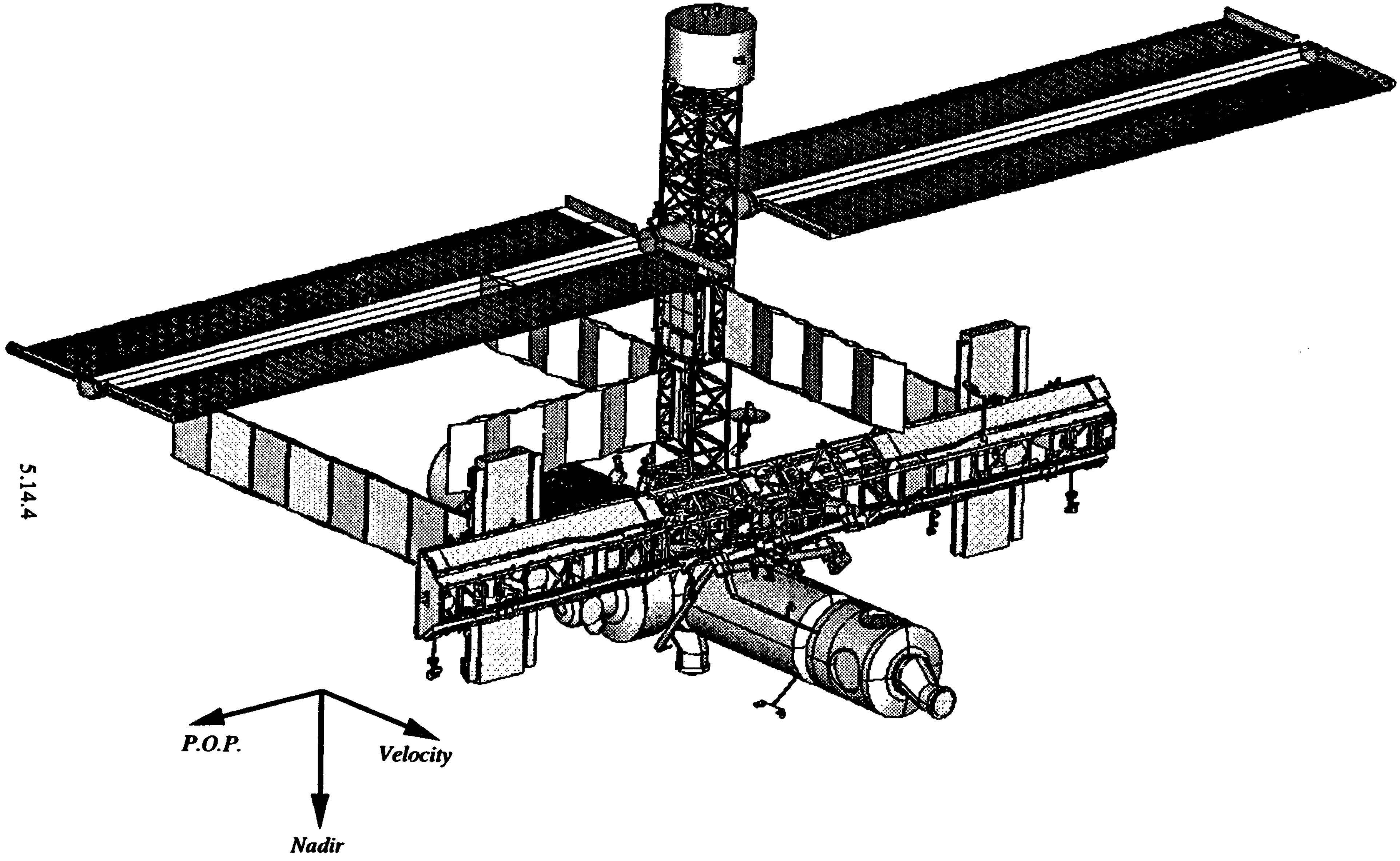


Figure 5.14.2–1 Stage 14 Configuration

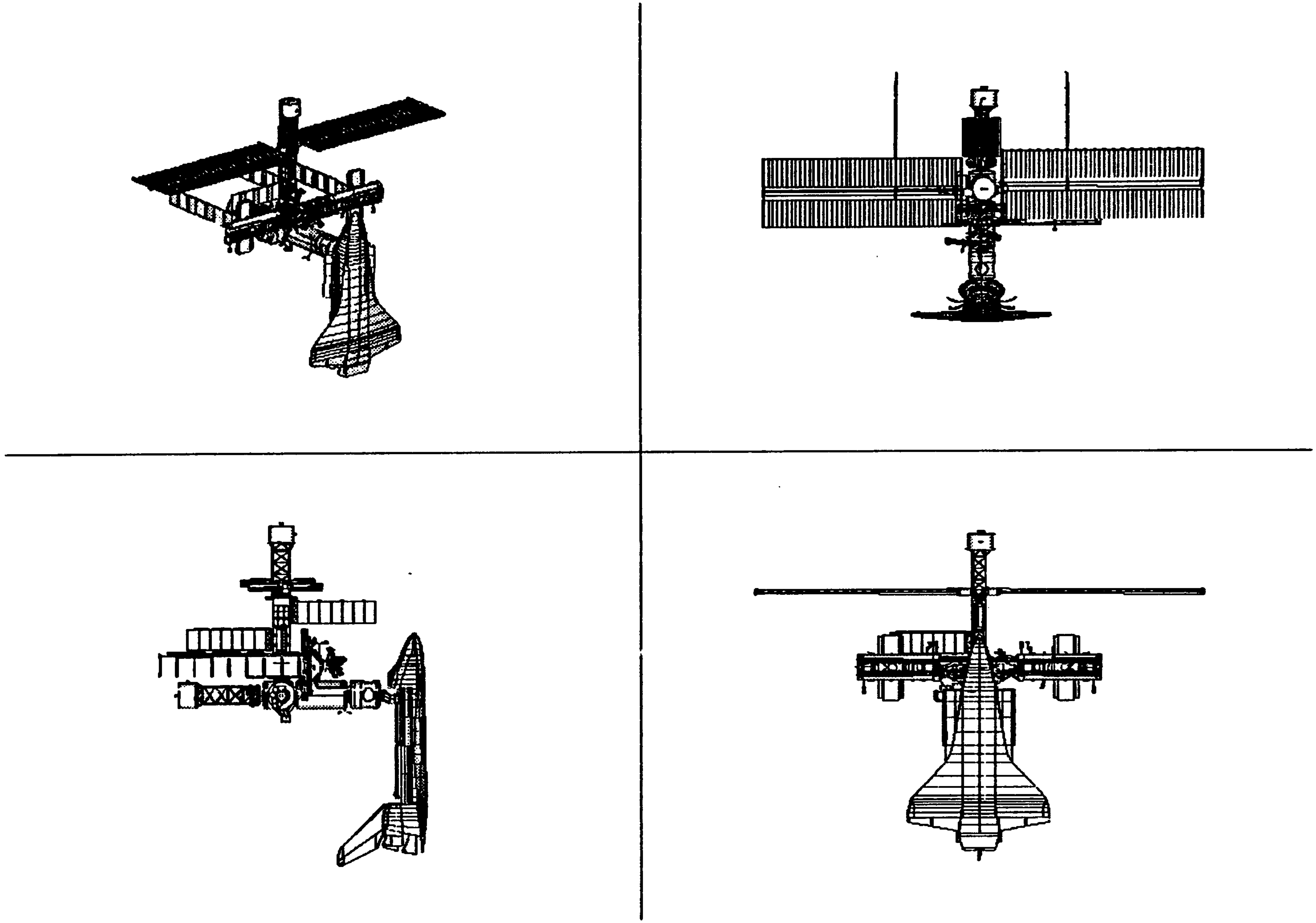


Figure 5.14.2–2 Stage 14 Configuration with Shuttle

5.14.4 Stage 14, Flight 11A Performance Characteristics

Stage 14, Flight 11A is assembled at a 215 n.mi. altitude in an LVLH flight mode with 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is April, 2000.

The Stage 14 steady state microgravity environment is depicted in figure 5.14.4-1. In a +2σ atmosphere (solar flux = 229.1, geomagnetic index = 21.2) this stage has a flight attitude of yaw = 0, pitch = 21.0, and roll = 0. Table 5.14.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2 sigma atmosphere. This configuration contains 9 ISPR racks in the 1 μg environment.

Table 5.14.4-1 Stage 14 US Lab Rack Steady State μg Level

Rack	Type	14
LAS-1	ISPR	0.8
LAS-2	ISPR	1.0
LAS-3	ISPR	1.2
LAS-4	ISPR	1.3
LAS-5	SYS	1.5
LAS-6	SYS	1.7
LAF-1	SYS	1.4
LAF-2	SYS	1.5
LAF-3	SYS	1.7
LAF-4	SYS	1.9
LAF-5	SYS	2.0
LAF-6	SYS	2.2
LAP-1	ISPR	0.9
LAP-2	ISPR	1.0
LAP-3	ISPR	1.2
LAP-4	ISPR	1.3
LAP-5	SYS	1.5
LAP-6	SYS	1.7
LAC-1	ISPR	0.4
LAC-2	ISPR	0.5
LAC-3	ISPR	0.7
LAC-4	ISPR	0.8
LAC-5	ISPR	1.0
LAC-6	SYS	1.1

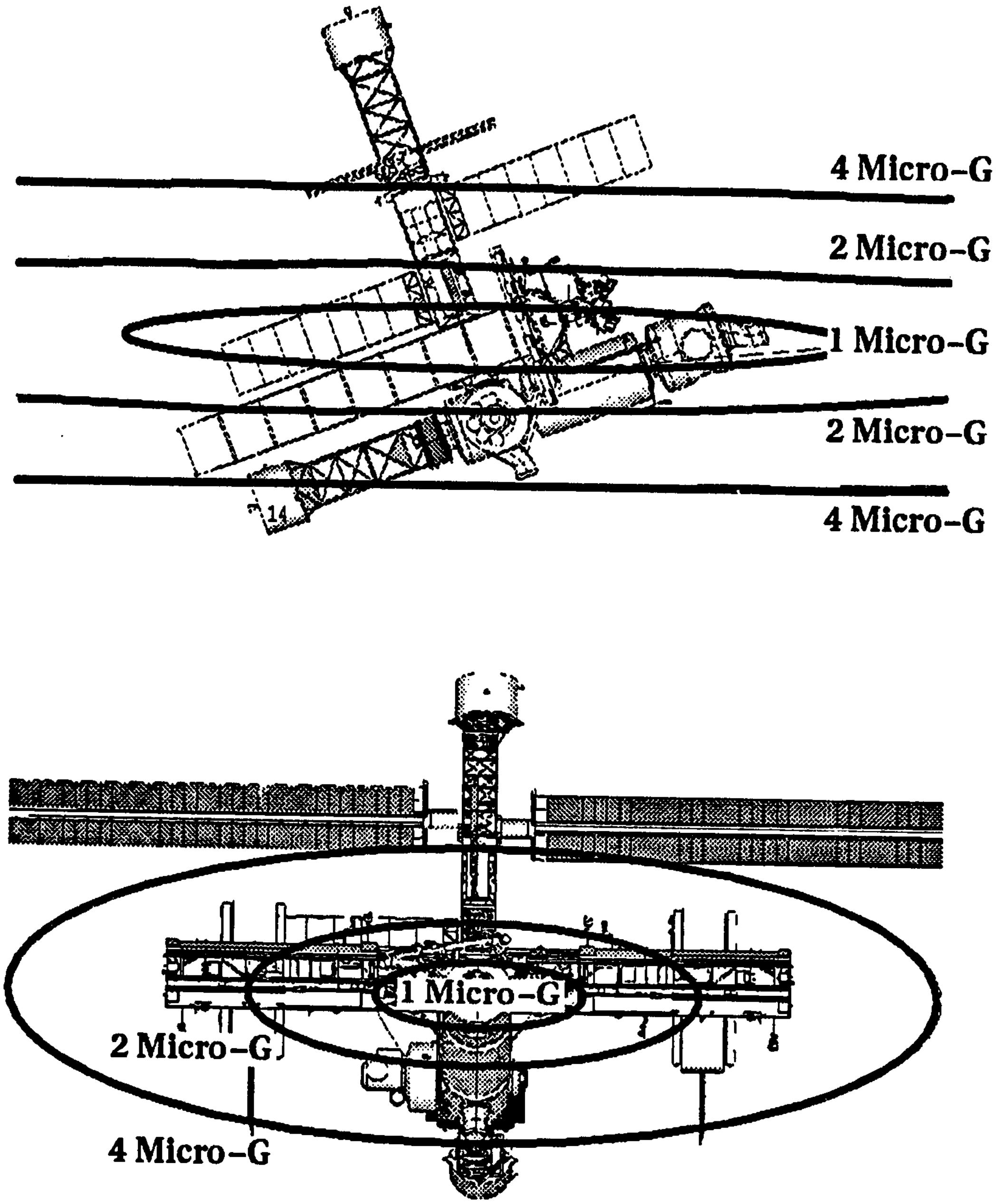


Figure 5.14.4-1 Stage 14 steady-state microgravity contours.

Table 5.14.4-2 summarizes the reboost lifetime characteristics of Stage 14 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 18.0 lbs/ft^2. The reboost was performed using the zenith bus, which has a reboost efficiency of 100%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.14.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
215	233	2,412	3,084	2,220	114

Probably due to the near spherical mass distribution properties of Stage 14, none of the PDR or CDR CMG attitude control algorithms were able to control the station attitude, even considering momentum wheel augmentation. This suggests that this configuration may require a customized attitude controller.

The control characteristics of Stage 14 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.14.4-2. Table 5.14.4-3 summarizes the control characteristics depicted in the plots.

Table 5.14.4-3 Control Characteristics Summary (attached Shuttle)

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
w/STS	0.0 degrees	-37.1 degrees	-0.2 degrees	± 0.2 degrees	3400 N-m-s

5.14.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees (with and without an attached Shuttle).

There is a small negative margin for the Shuttle manifest which will require weight reduction or utilization of reserve performance margins.

There is a possibility of some indirect plume impingement of the aft P6 and S1 radiators from the aft bus attitude control thrusters.

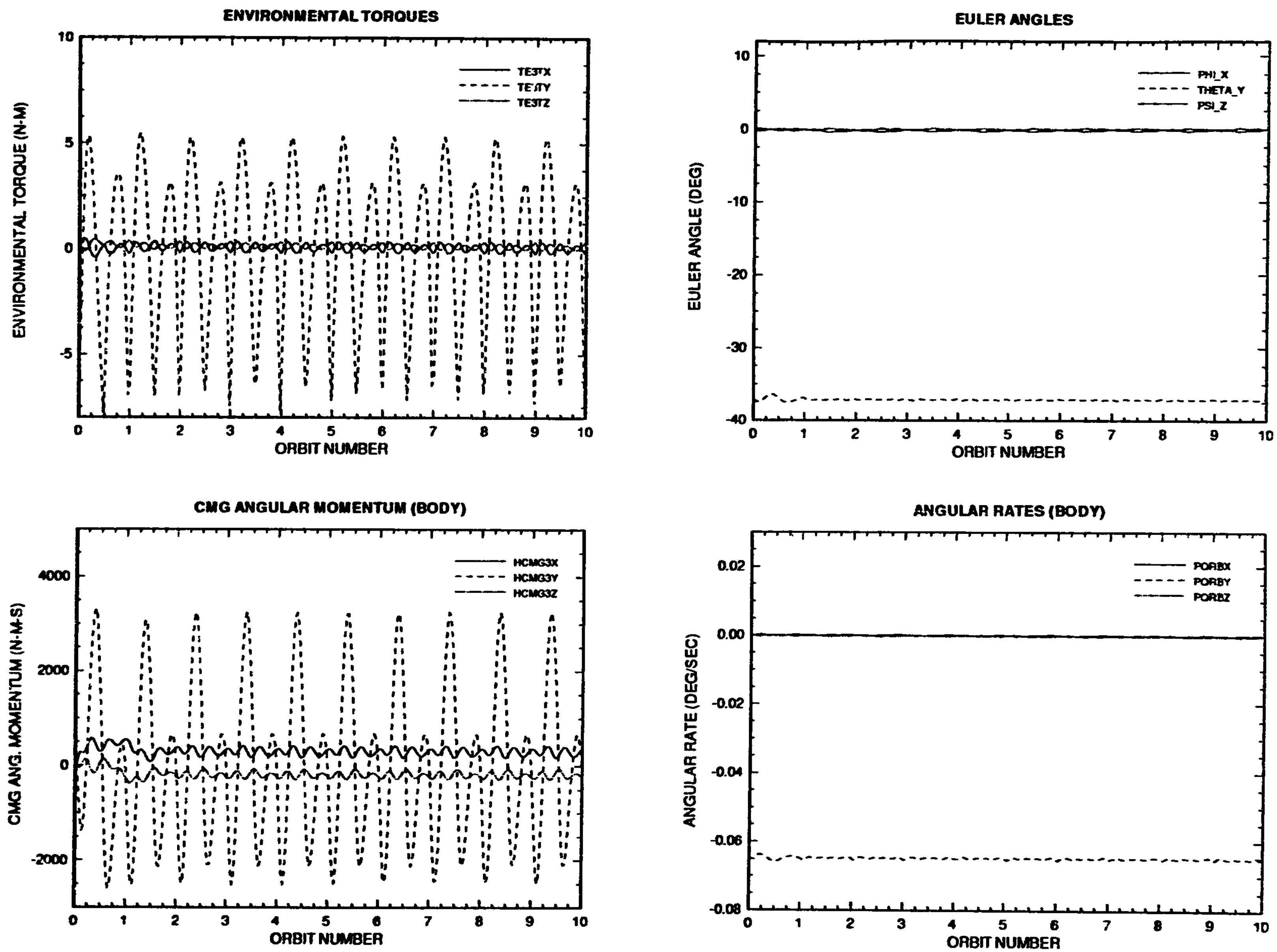


Figure 5.14.4-2 Stage 14 control plots with Shuttle attached.

5.15 Stage 15 Flight Characterization

5.15.1 Stage 15 - Flight UF-3 Shuttle Flight Manifest

The third utilization flight supplies additional ISPR racks in the MPLM to exchange with existing Lab ISPR racks. Table 5.15.1-1 lists the Shuttle Flight Manifest for Stage 15 - Flight UF-3. The total mass of the station hardware to orbit is 12890 lbs and FSE mass of 10705 lbs. The second section of the table shows the Shuttle Performance and hardware/ consumables required for the mission resulting in the net Shuttle Lift Capability of 26294 lbs to 220 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yieldss a mission flight margin of 2699 lbs.

5.15.2 Stage 15 Configuration

Figure 5.15.2-1 displays the isometric view of Stage 15 after the Shuttle departs and the scheduled assembly is completed. Figure 5.15.2-2 shows the front, side, top and isometric views of Stage 15 with the Shuttle attached.

5.15.3 Flight UF-3 Assembly Operations Description

Rendezvous of the Shuttle with the Stage 14 occurs along +V bar at an altitude of 220 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight UF-3 is a 12 day mission with 0 EVAs. The SRMS unberths the MPLM from the Shuttle payload bay and installs it on the Node 2 nadir port CBM. Upon completion of the rack exchange, the MPLM is returned to payload bay.

Following separation, Stage 15 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 14 functionality, plus:

- One additional stowage rack brought to orbit
- No other functional changes

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*0 crew-hours*	
Resources Required:	*Power:*	*12,232 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		711 W	*(CSA)*
	Thermal:	*TBD W*	
	EVA:	*0 crew-hours*	

Table 5.15.1-1 Stage 15 - Flight UF-3 Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
MPLM		10705
ISPRs (lab)	12000	
JEM ELM PS / US Stowage Rack 3	890	
subtotal	**12890**	**10705**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		0
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-1324
APCU-I	714	
ROFU	450	
Misc hardware	160	
	1324	
Variable Shuttle Consumables		-3033
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	330	
5th N2 tanks (@128 lbs/N2)	128	
5th Cryo Tank & Fluid	1575	
	3033	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1100
Maintenance Reserve		-400
Total Shuttle Lift Capability		**26294**

Mission Flight Margin		**2699**

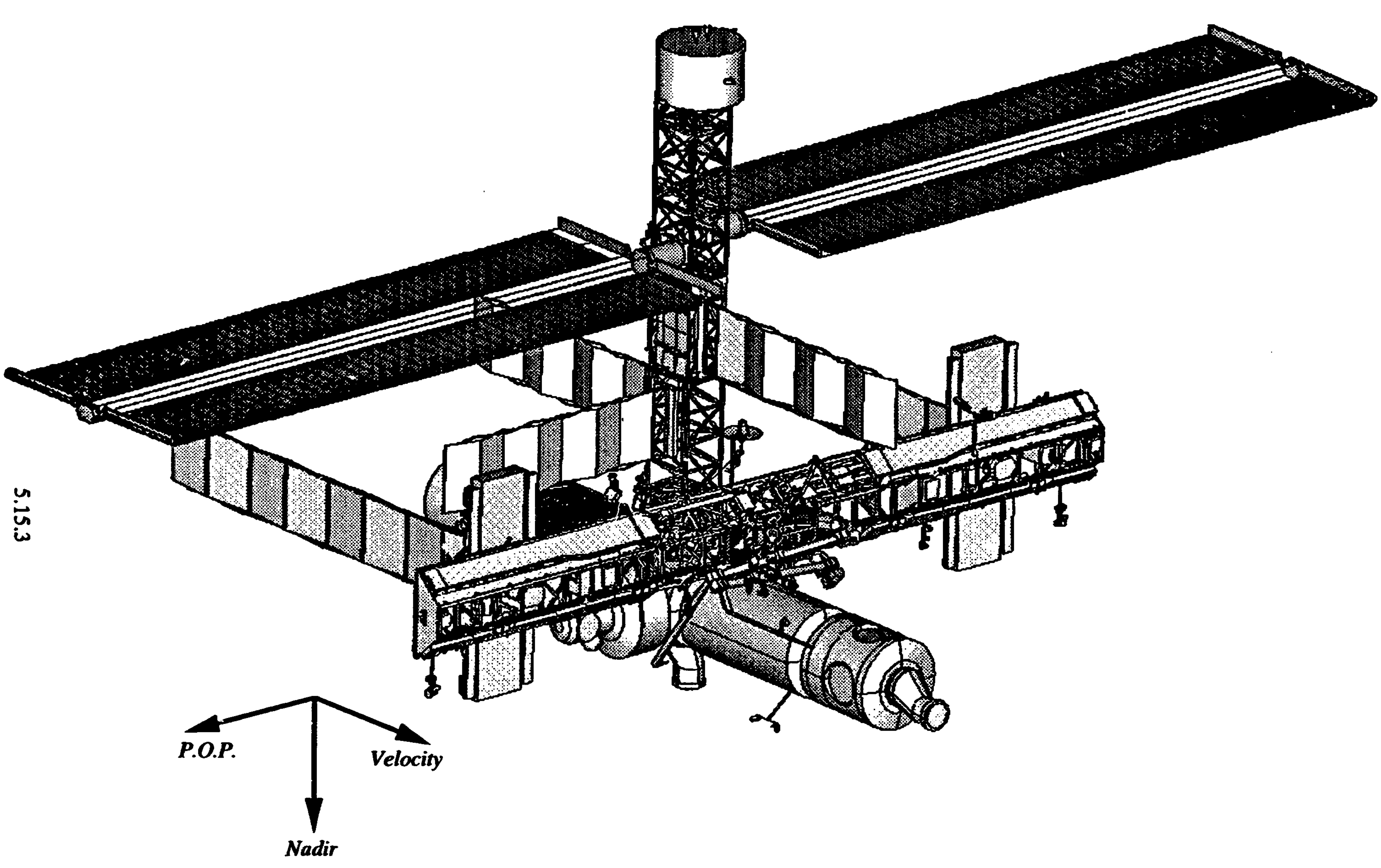


Figure 5.15.2-1 Stage 15 Configuration

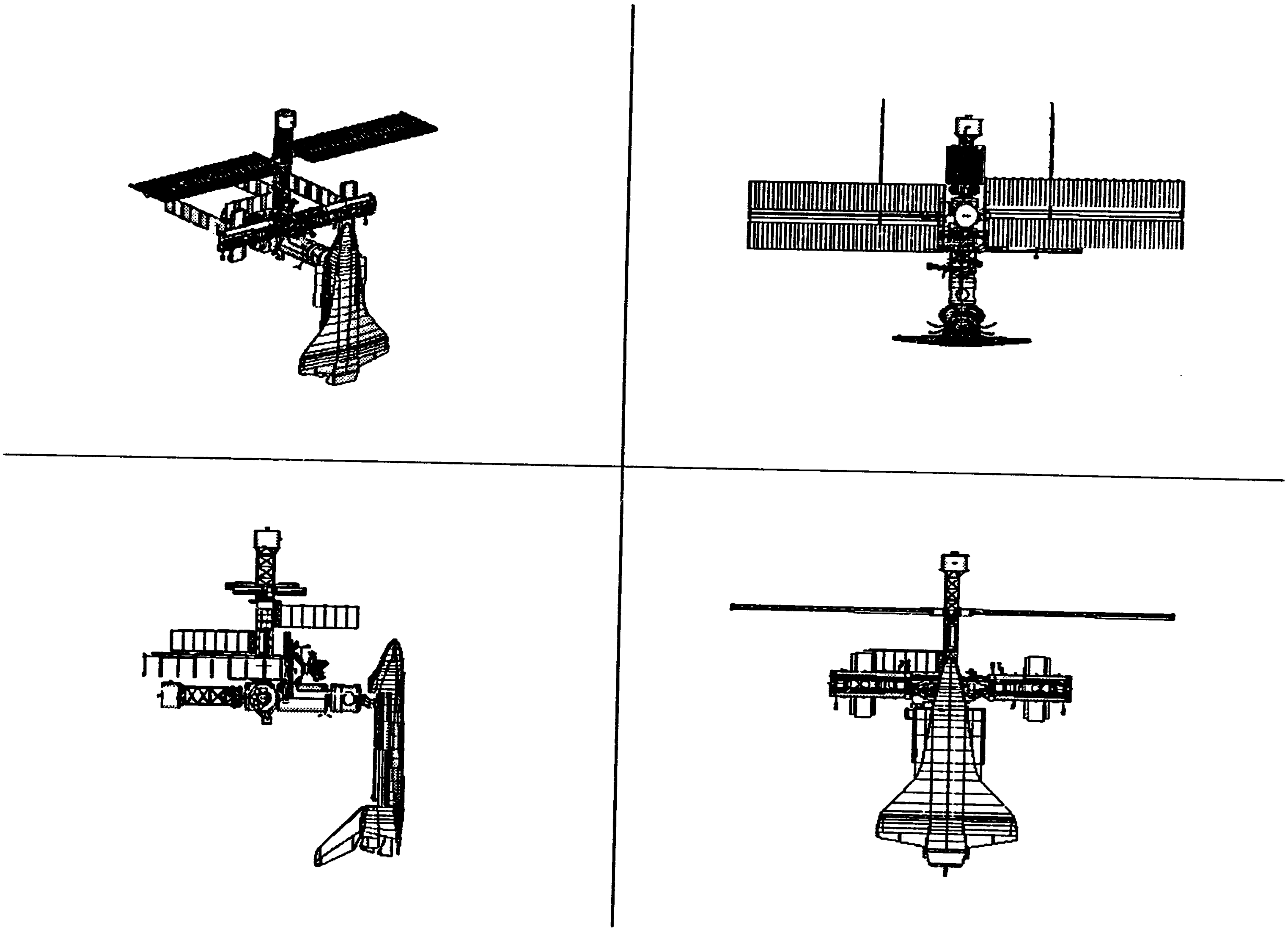


Figure 5.15.2-2 Stage 15 Configuration with Shuttle

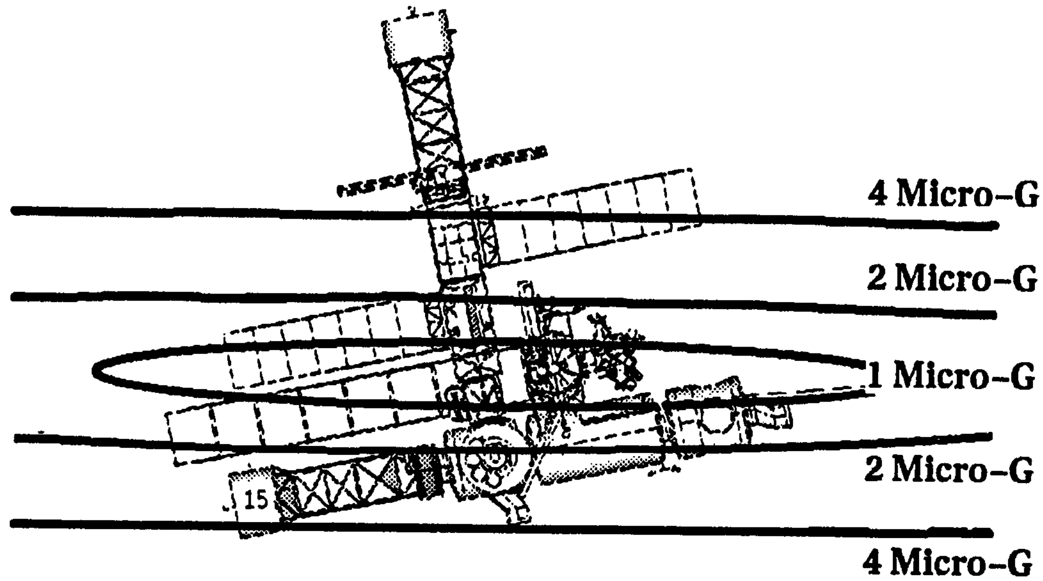
5.15.4 Stage 15, Flight UF-3 Performance Characteristics

Stage 15, Flight UF-3 is assembled at a 220 n.mi. altitude in an LVLH flight mode with 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is June, 2000.

The Stage 15 steady state microgravity environment is depicted in figure 5.15.4-1. In a $+2\sigma$ atmosphere (solar flux = 227.6, geomagnetic index = 20.7) this stage has a flight attitude of yaw = 0, pitch = 11.3, and roll = 0. Table 5.15.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given $+2\sigma$ atmosphere. This configuration contains 4 ISPR racks in the 1 μg environment.

Table 5.15.4-1 Stage 15 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.3
LAS-2	ISPR	1.4
LAS-3	ISPR	1.5
LAS-4	ISPR	1.6
LAS-5	SYS	1.7
LAS-6	SYS	1.8
LAF-1	SYS	1.9
LAF-2	SYS	2.0
LAF-3	SYS	2.1
LAF-4	SYS	2.2
LAF-5	SYS	2.3
LAF-6	SYS	2.4
LAP-1	ISPR	1.3
LAP-2	ISPR	1.4
LAP-3	ISPR	1.5
LAP-4	ISPR	1.6
LAP-5	SYS	1.7
LAP-6	SYS	1.8
LAC-1	ISPR	0.7
LAC-2	ISPR	0.8
LAC-3	ISPR	0.9
LAC-4	ISPR	1.0
LAC-5	ISPR	1.1
LAC-6	SYS	1.2



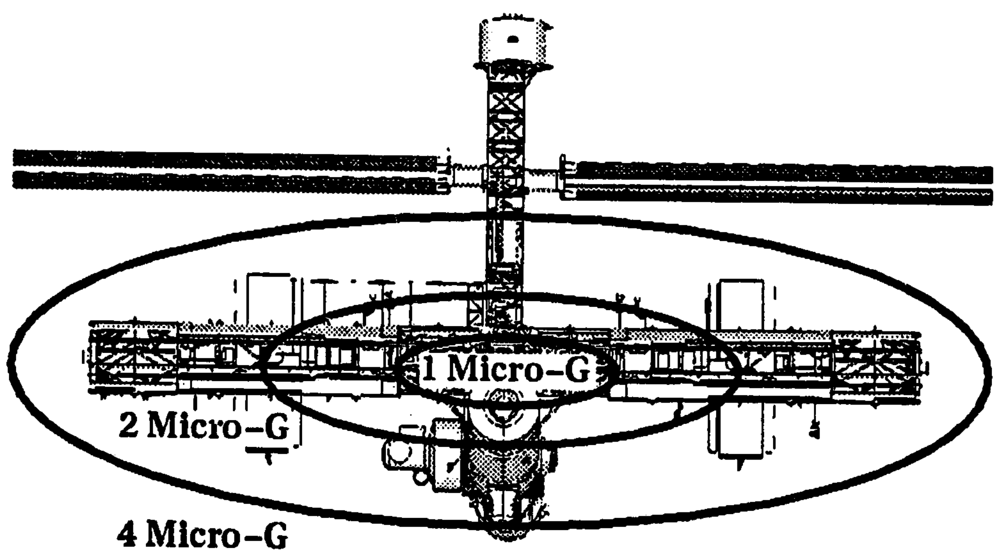


Figure 5.15.4-1 Stage 15 steady-state microgravity environment contours.

Table 5.15.4-2 summarizes the reboost lifetime characteristics of Stage 15 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 18.5 lbs/ft^2. The reboost was performed using the zenith bus, which has a reboost efficiency of 100%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.15.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
220	230	1,301	3,084	920	140

The control characteristics of flight UF-3 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.15.4-2. The CMGs were augmented with a 4000 N-m-s momentum wheel. Table 5.15.4-3 summarizes the control characteristics depicted in the plots.

Table 5.15.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	0.0 degrees	25.7 degrees	0.1 degrees	± 2.0 degrees	3000 N-m-s
w/STS	0.0 degrees	-37.1 degrees	-0.3 degrees	± 0.2 degrees	3400 N-m-s

The control characteristics of Stage 15 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.15.4-3. No momentum wheel was required. Table 5.15.4-3 summarizes the control characteristics depicted in the plots.

5.15.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees (with and without an attached Shuttle).

There is a possibility of some indirect plume impingement of the aft P6 and S1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

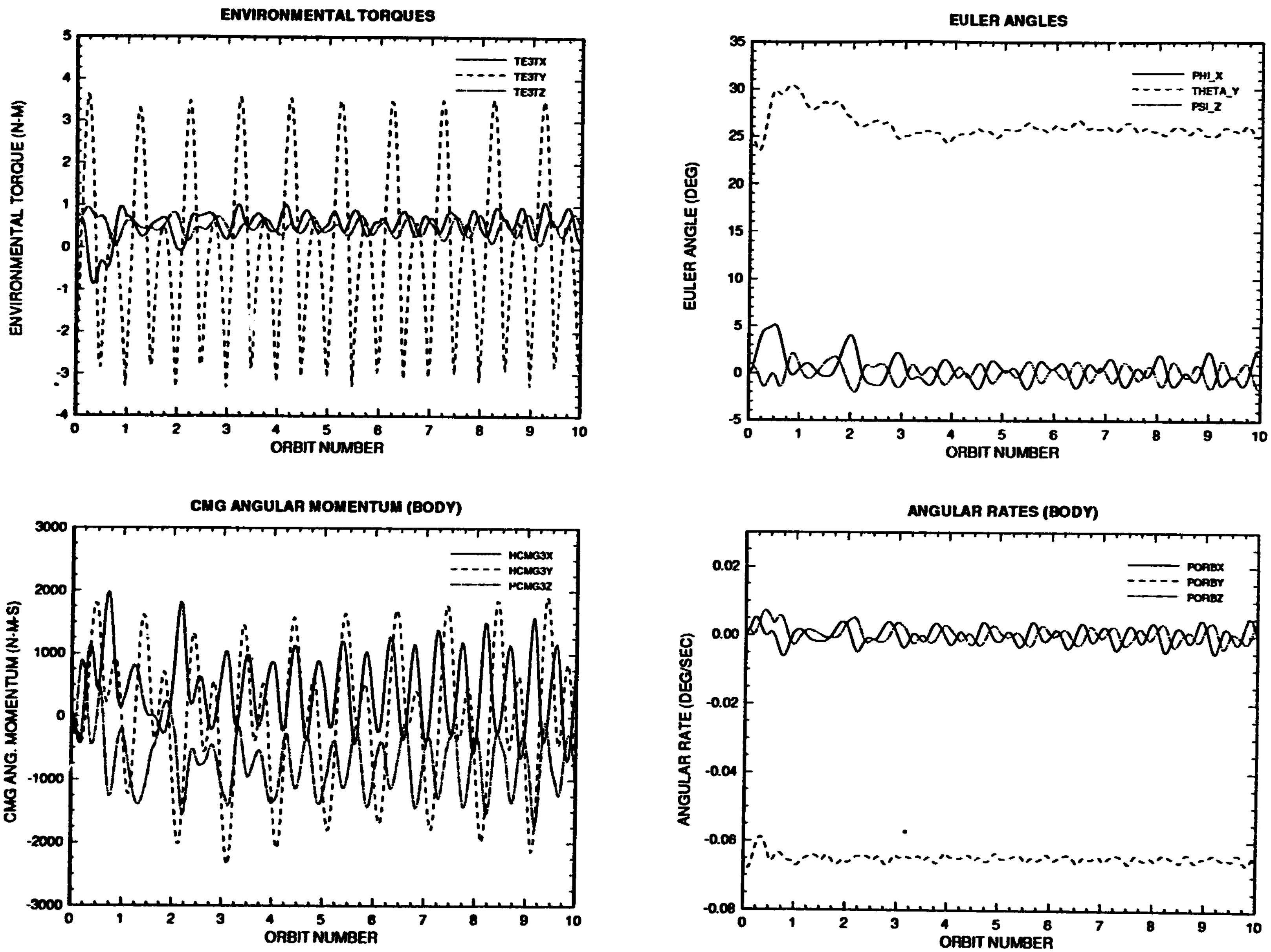


Figure 5.15.4-2 Stage 15 control plots without Shuttle attached.

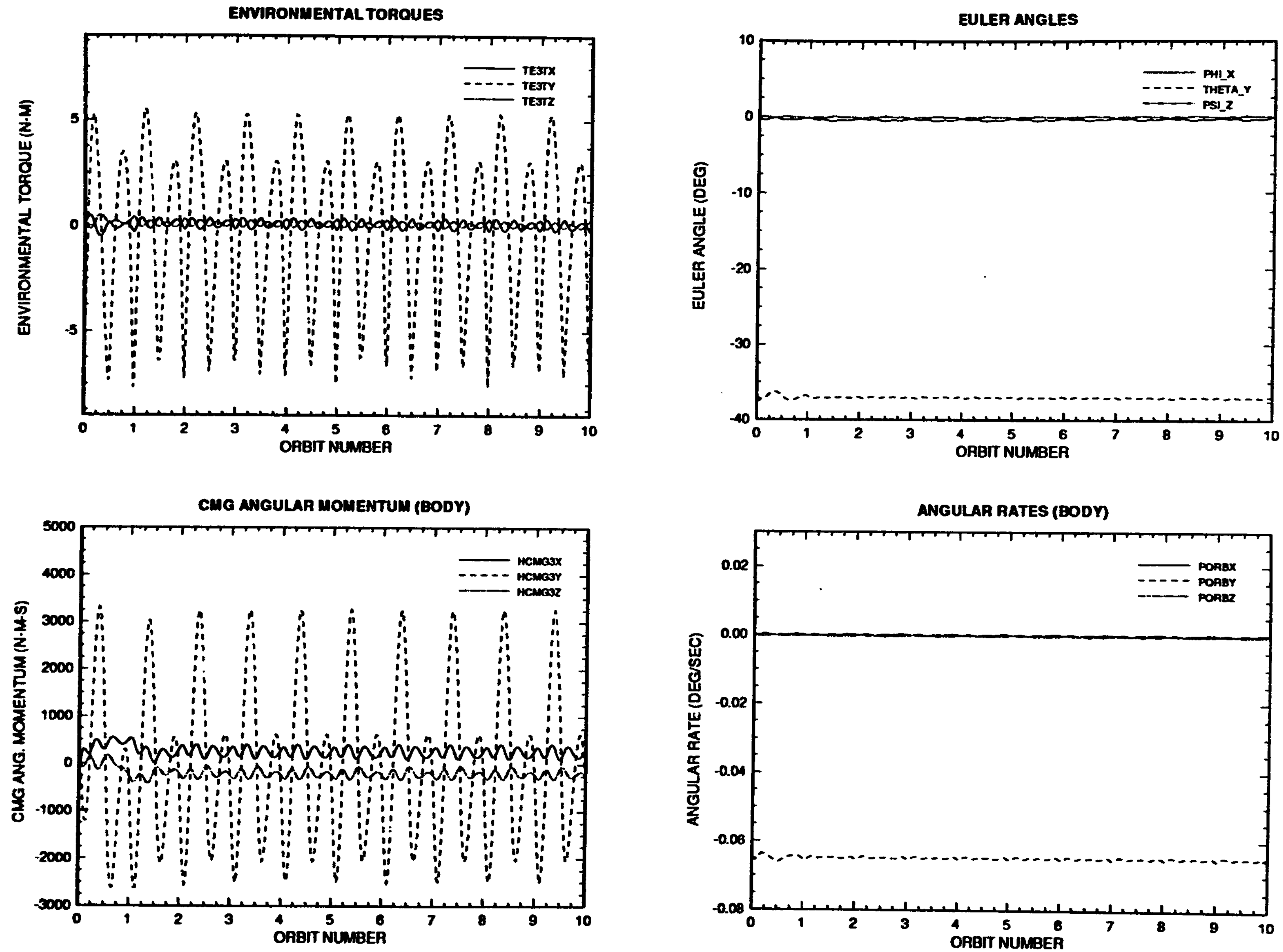


Figure 5.15.4-3 Stage 15 control plots with Shuttle attached.

5.16 Stage 16 Flight Characterization

5.16.1 Stage 16 - Flight 1J/A Shuttle Flight Manifest

This assembly flight delivers the first NASDA element, the Japanese Experiment Module Experiment Logistics Module Pressurized Section (JEM ELM PS). Table 5.16.1-1 lists the Shuttle Flight Manifest for Stage 16 - Flight 1J/A. The total mass of the station hardware to orbit is 22810 lbs, and the FSE required is 4095 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 26084 lbs to 220 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a negative mission flight margin of -821 lbs.

5.16.2 Stage 16 Configuration

Figure 5.16.2-1 displays the isometric view of Stage 16 after the Shuttle departs and the scheduled assembly is completed. Figure 5.16.2-2 shows the front, side, top and isometric views of Stage 16 with the Shuttle attached.

5.16.3 Flight 1 J/A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 15 occurs along +V bar at an altitude of 220 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 1 J/A is a 10 day mission with 6 EVAs. The deferred EVAs from flight 11A are completed prior to installing the first NASDA element. The most critical of those deferred tasks is the relocation of the S-band RF group on P6 to the P1 ITS. The SRMS unberths the JEM ELM-PS from the Shuttle payload bay and hands off the element to the SSRMS. The SSRMS attaches the JEM ELM-PS to the Node 2 zenith CBM. Two EVAs are required to replace two HPGAs (O2) and return the spent HPGAs, with the ULC, to the payload bay. The SPDM is also installed on the MBS PDGF and a dynamic checkout is performed prior to departure.

Following separation, Stage 16 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 15 functionality, plus:

- Improved S-band Coverage
- One additional stowage rack brought to orbit
- Delivers JEM Experiment Logistics Module - Pressurized Section
- Airlock resupply - HP to O2 tanks replaced
- SPDM installed and activated

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*72 crew-hours*	
Resources Required:	*Power:*	*12,232 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		229 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*57:40 crew-hours*	

Table 5.16.1-1 Stage 16 - Flight 1J/A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
JEM ELM PS		
JEM PM DMS 1 Rack	939	
JEM PM System Stowage 1 Rack	824	
JEM PM RMS Workstation	939	
JEM PM THC/TCS 1 Rack	1164	
JEM PM EPS 1 Rack	866	
JEM PM Workstation Rack	928	
JEM ELM PS Module Core	9379	
middeck equipment	133	
JEM PM ISPR 1 Rack	1499	
JEM PM ISPR 2 Rack	1499	
SPDM	3490	1420
ULC -A		2675
O2 tanks (on ULC)	1150	
subtotal	**22810**	**4095**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		0
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-990
Additional Attach Hardware	990	
	990	
Variable Shuttle Consumables		-3307
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	220	
5th & 6th N2 tanks (@128 lbs/N2)	512	
5th Cryo Tank & Fluid	1575	
	3307	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1310
Maintenance Reserve		-460
Total Shuttle Lift Capability		**26084**

Mission Flight Margin		**-821**

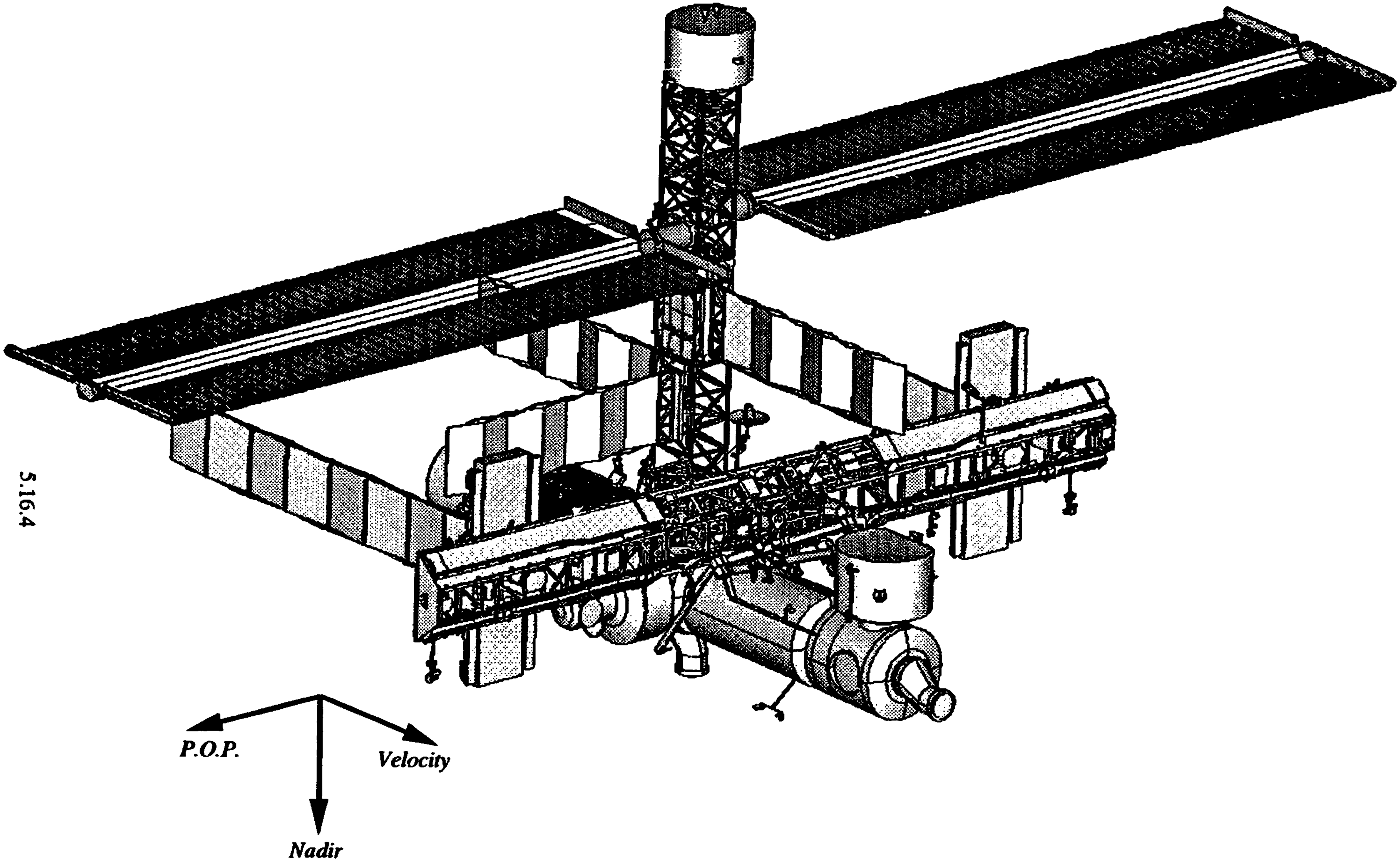


Figure 5.16.2-1 Stage 16 Configuration

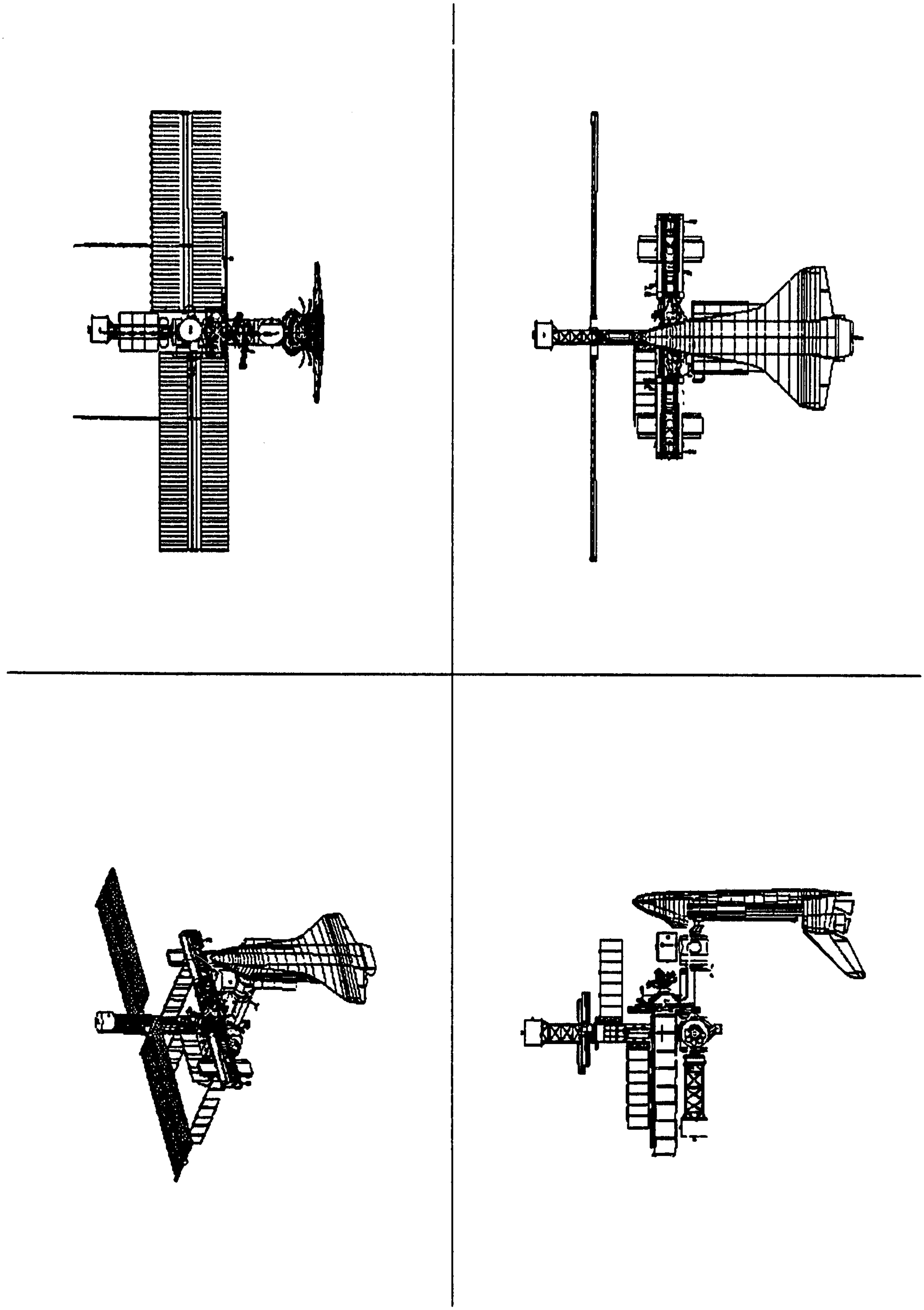


Figure 5.16.2-2 Stage 16 Configuration with Shuttle

5.16.4 Stage 16, Flight 1J/A Performance Characteristics

Stage 16, Flight 1J/A is assembled at a 220 n.mi. altitude in an LVLH flight mode with 2 single axis articulating PV arrays perpendicular to the orbit plane. The nominal launch date is August, 2000.

No microgravity levels were determined for the station ISPR racks since the stage could not be controlled.

Table 5.16.4-1 summarizes the reboost lifetime characteristics of Stage 16 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 19.5 lbs/ft^2. The reboost was performed using the aft bus, which has a reboost efficiency of 93%. For this stage there is insufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.16.4-1 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
220	238	2,784	299	920	131

Probably due to the near spherical mass distribution properties of Stage 16, none of the PDR or CDR CMG attitude control algorithms were able to control the station attitude, even considering momentum wheel augmentation. This suggests that this configuration may require a customized attitude controller.

The control characteristics of Stage 16 (attached Shuttle) under design atmosphere conditions using the JSC/UT nominal controller (attitude emphasis) are displayed in figure 5.16.4-1. Table 5.16.4-2 summarizes the control characteristics depicted in the plots.

Table 5.16.4-2 Control Characteristics Summary (Shuttle attached)

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
w/STS	2.7 degrees	-37.9 degrees	-0.1 degrees	± 0.1 degrees	2400 N-m-s

5.16.5 Issues and Concerns

The CMG control simulations for the unmated configuration all eventually went unstable. The closeness of all three body axes inertias along with large pitch aerodynamic torques result in a constant pitch torque imbalance. The only way to eliminate the imbalance is to rotate the configuration 90 degrees in pitch so that the pitch aerodynamic torques are nearly zero. This non-standard attitude would result in a poor microgravity environment but could probably be controlled by CMGs utilizing customized control algorithms.

This stage has a pitch flight attitude that exceeds ±15 degrees (with an attached Shuttle).

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

For this stage there is insufficient propellant reserve on the bus to meet the skip cycle contingency reboost requirement.

There is a small negative margin for the Shuttle manifest which will require weight reduction or utilization of reserve performance margins.

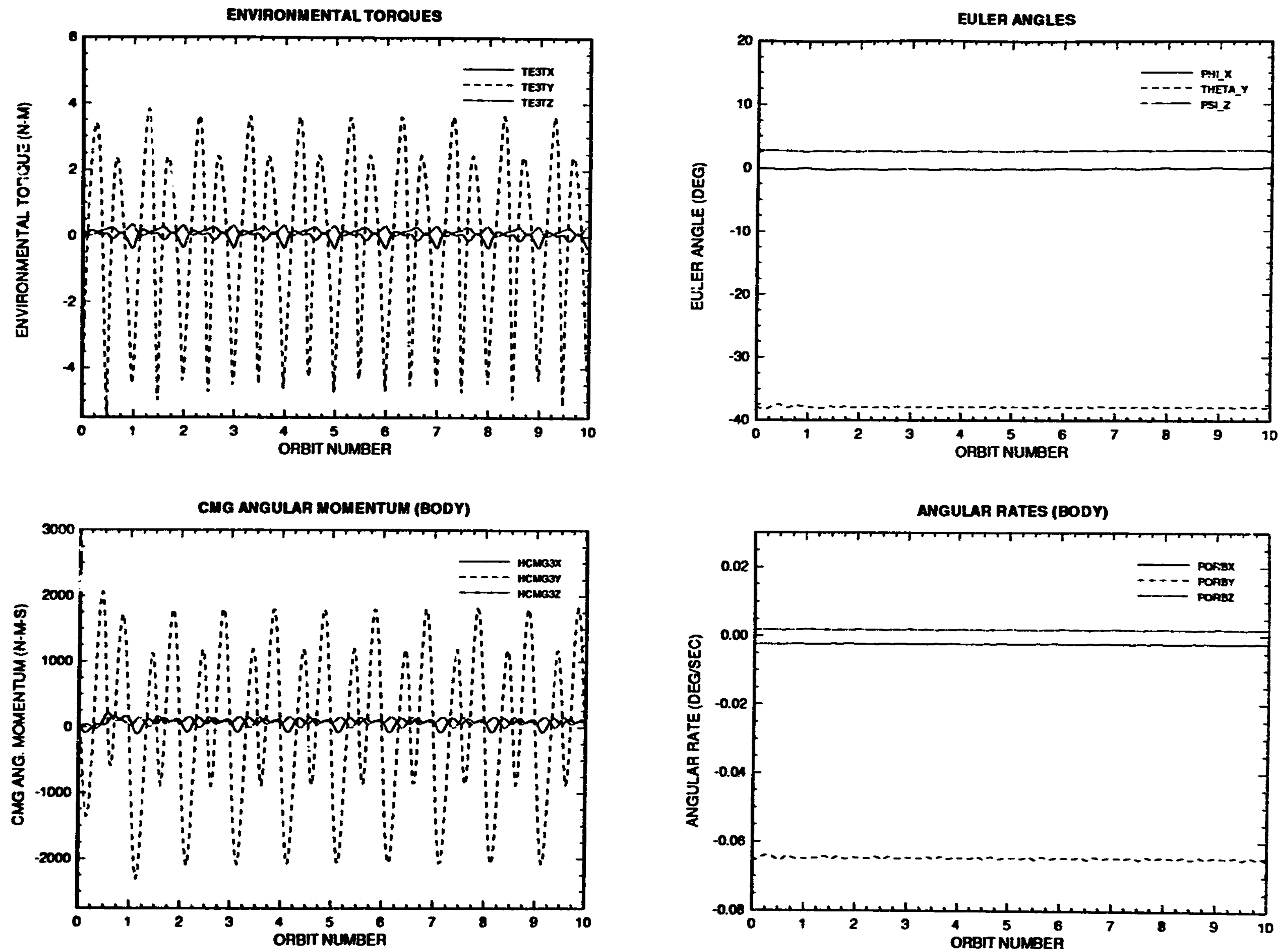


Figure 5.16.4-1 Stage 16 control plots with Shuttle attached.

5.17 Stage 17 Flight Characterization

5.17.1 Stage 17 - Flight 12A Shuttle Flight Manifest

The shuttle delivers the P3/P4 truss segment with the port inboard photovoltaic (PV) arrays. Table 5.17.1-1 lists the Shuttle Flight Manifest for Stage 17 - Flight 12A. The total mass of the station hardware to orbit is 32781 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 31775 lbs to 220 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a negative mission flight margin of -1006 lbs.

5.17.2 Stage 17 Configuration

Figure 5.17.2-1 displays the isometric view of Stage 17 after the Shuttle departs and the scheduled assembly is completed. Figure 5.17.2-2 shows the front, side, top and isometric views of Stage 17 with the Shuttle attached.

5.17.3 Flight 12A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 16 occurs along +V bar at an altitude of 220 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 12A is an 8 day mission with 2 EVAs. The SRMS unberths the P3/P4 ITS from the Shuttle payload bay and hands off to the SSRMS which installs the element on P1 ITS. The EVAs during this flight include the installation of the structural elements around the Solar Alpha Rotary Joint (SARJ) that ensure the structural integrity of the joint. Due to the EVA time constraint on this flight, no EPS preparation or activation occurs until the following flight. The final EVA includes the deployment of the port ULCAs.

Following separation, Stage 17 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 16 functionality, plus:

- P3 ITS and P4 power module delivered to orbit (partially installed, not activated)

Resources Available:	*Power:*	*15,800 W*	
	Thermal:	*TBD*	
	EVA:	*24 crew-hours*	
Resources Required:	*Power:*	*12,232 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		229 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*13:54 crew-hours*	

Table 5.17.1-1 Stage 17 - Flight 12A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
P3 TRUSS SEGMENT	4410	
P3 UTILITY TRAYS	1417	
SARJ STATOR	920	
SARJ UTA	920	
ULC ATTACH STRUCTURE	344	
ULC ATTACH STRUCTURE	344	
P3 ROTARY BULKHEAD	492	
SARJ ROTOR	920	
P4 TRUSS SEGMENT	9482	
BG DEPLOYED	1338	
IEA BATTERIES (8 batteries)	4968	
P3/P4 BARS	463	
P4 IEA Radiator	1474	
PIA PV Array	2646	
PIF PV Array	2646	
subtotal	**32781**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		0
Additional Shuttle Performance Enhancements		1500
Variable Integrated Hardware		-238
Variable Shuttle Consumables		-238
Food & Gear (-55 lbs/day over 6)	110	
5th & 6th N2 tanks (@128 lbs/N2)	128	
	238	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-400
Total Shuttle Lift Capability		**31775**
Mission Flight Margin		**-1006**

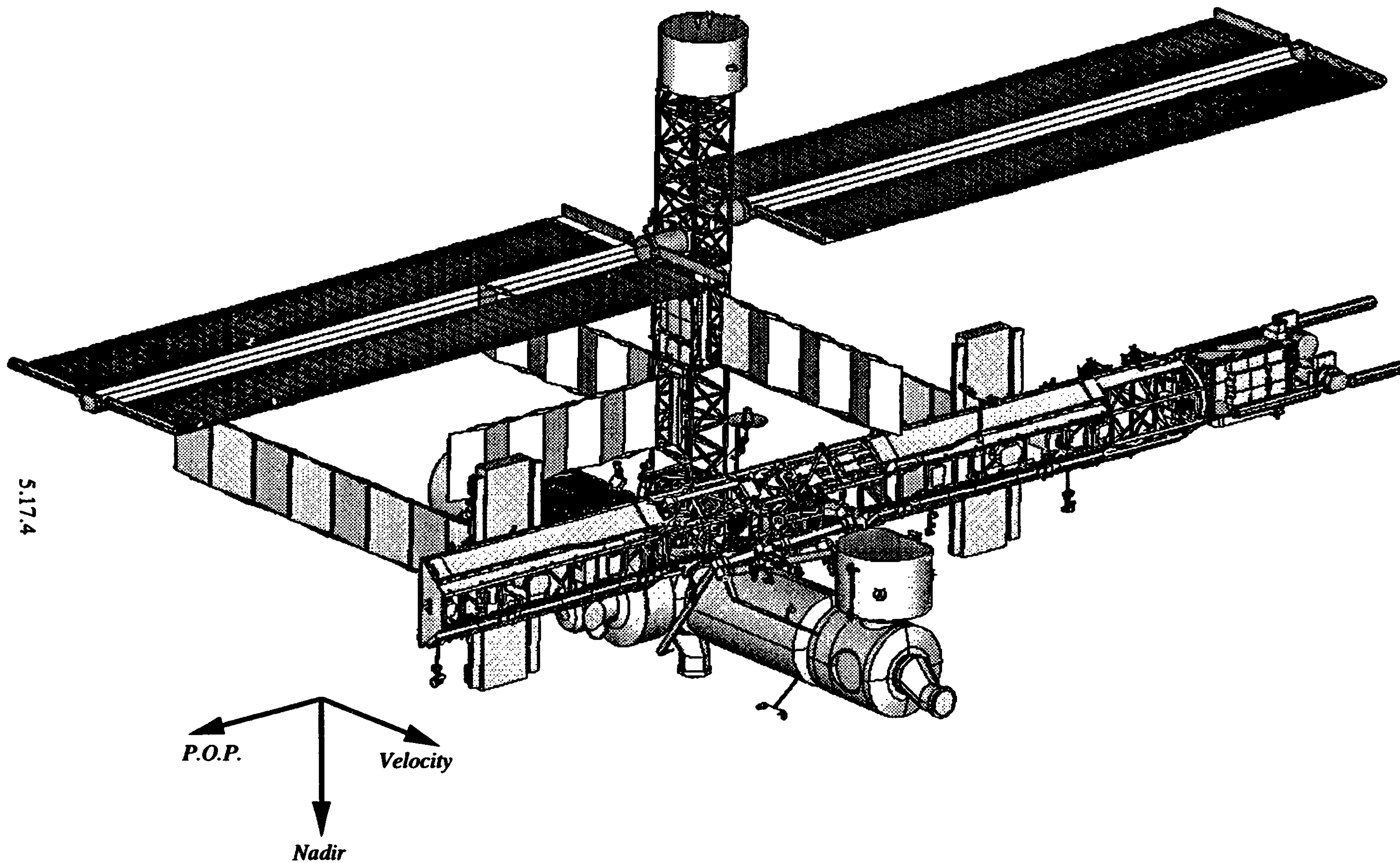


Figure 5.17.2–1 Stage 17 Configuration

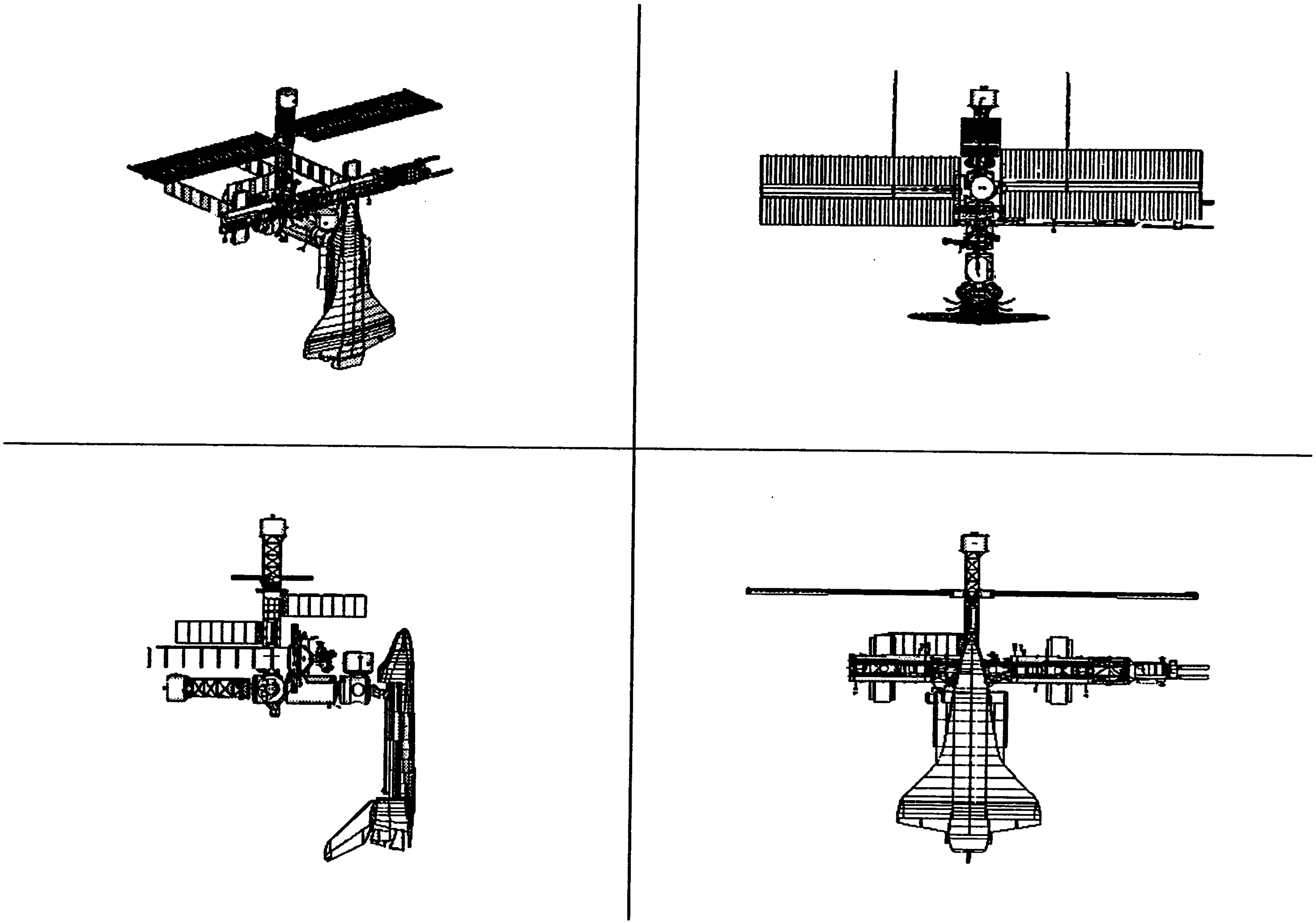


Figure 5.17.2-2 Stage 17 Configuration with Shuttle

5.17.4 Stage 17, Flight 12A Performance Characteristics

Stage 17, Flight 12A is assembled at a 230 n.mi. altitude in an LVLH flight mode with two PV arrays which are not deployed and two single axis PV array perpendicular to the orbit plane. The nominal launch date is October, 2000.

The Stage 17 steady state microgravity environment is depicted in figure 5.17.4-1. In a +2σ atmosphere (solar flux = 218.6, geomagnetic index = 22.3) this stage has a flight attitude of yaw = 10.0, pitch = 0.0, and roll = -5.0. Table 5.17.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. Under these conditions, this configuration does not provide any of the US Lab ISPR racks a 1 μg environment.

Table 5.17.4-1 Stage 17 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.9
LAS-2	ISPR	1.9
LAS-3	ISPR	1.9
LAS-4	ISPR	1.9
LAS-5	SYS	1.8
LAS-6	SYS	1.8
LAF-1	SYS	2.4
LAF-2	SYS	2.4
LAF-3	SYS	2.4
LAF-4	SYS	2.4
LAF-5	SYS	2.4
LAF-6	SYS	2.4
LAP-1	ISPR	1.8
LAP-2	ISPR	1.8
LAP-3	ISPR	1.8
LAP-4	ISPR	1.8
LAP-5	SYS	1.8
LAP-6	SYS	1.8
LAC-1	ISPR	1.2
LAC-2	ISPR	1.2
LAC-3	ISPR	1.2
LAC-4	ISPR	1.2
LAC-5	ISPR	1.2
LAC-6	SYS	1.2

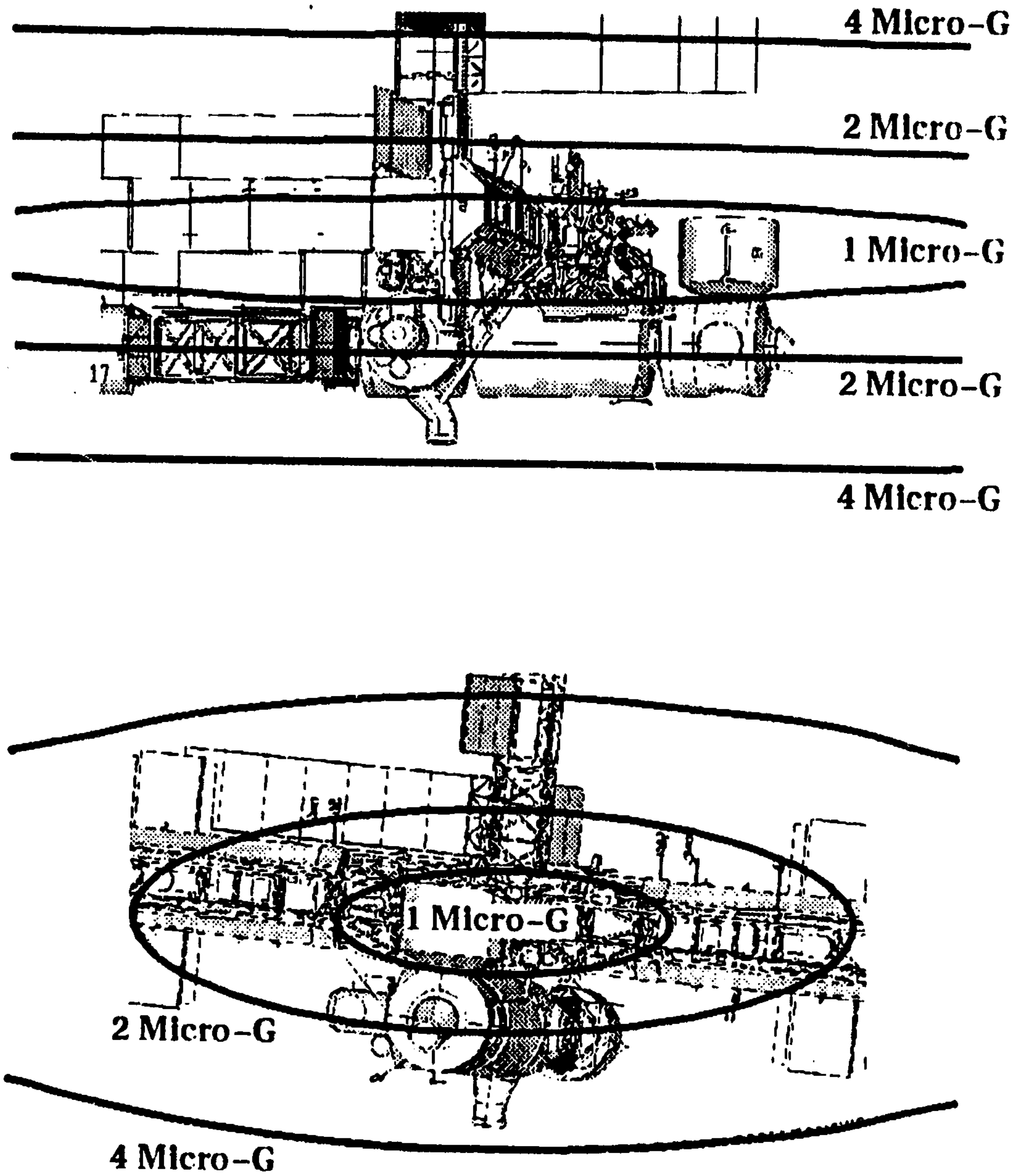


Figure 5.17.4-1 Stage 17 steady-state microgravity environment contours.

Table 5.17.4-2 summarizes the reboost lifetime characteristics of Stage 17 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 20.3 lbs/ft^2. There is insufficient propellant in either bus to perform the required reboost maneuver. The amount of propellant required to perform the reboost maneuver was calculated as if using the aft bus, which has a reboost efficiency of 94%. For this stage there is insufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.17.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	240	1,709	-1,410	920	201

The control characteristics of Stage 17 under design atmosphere conditions using the PDR yaw bias controller are displayed in figure 5.17.4-2. The CMGs were augmented with a 7500 N-m-s momentum wheel. Table 5.17.4-3 summarizes the control characteristics depicted in the plots.

Table 5.17.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	13.8 degrees	1.8 degrees	-10.1 degrees	± 2.0 degrees	9,000 N-m-s
w/STS	-13.9 degrees	-37.6 degrees	6.3 degrees	± 0.2 degrees	2,000 N-m-s

The control characteristics of Stage 17 (attached Shuttle) under design atmosphere conditiond using the PDR nominal controller (attitude emphasis) are displayed in figure 5.17.4-3. No momentum wheel was required. Table 5.17.4-3 summarizes the control characteristics depicted in the plots.

As discussedin Section 5.10.4 the Shuttle is required to perform periodic attitude maneuvers during certain solar geometry conditions while mated with the in order to avoid exceeding thermal loads on the Orbiter. The maneuver must be able to be performed using the RCS thrusters from *either* bus starting from Stage 10.

Three sample mated configurations were selected for analysis : Stage 10, when the upper bus is delivered, Stage 17/Flight 12A, and Stage 36/Flight 19A. The CDR RCS attitude maneuver control algorithm was employed. A 180 degree yaw maneuver was performed.

It should be noted that the total impulse per attitude control thruster is 134,000 lb_f-sec.

For Stage 17, a 0.1 degree/sec rate limit was also utilized. The 180 degree yaw maneuver took approximately 1800 seconds (~1/3 orbit) for both the aft and upper bus. There was about a 17 degree overshoot in the yaw channel, and under 5 degrees in pitch. Both upper and aft buses required about 95 lb. of fuel to perform the maneuver. By and large, all four

thrusters on each bus were selected approximately equally by the RCS CDR control algorithm. Table 5.17.4-1 lists the fuel and total impulse requirements.

Table 5.17.4.1 Yaw Maneuver Fuel and Impulse Requirements

Bus	Fuel Used (lb.) / Total Impulse (lb.-sec)				Total Fuel (lb.)
	Nozzle #3	Nozzle #4	Nozzle #5	Nozzle #6	
aft	24.5/ 7215	23.1/ 6825	23.4/ 6890	22.7/ 6695	93.8
zenith	22.6/ 6656	21.4/ 6311	25.7/ 7578	24.9/ 7338	94.6

5.17.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees (with an attached Shuttle).

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

For this stage there is insufficient propellant reserveon the bus to meet the skip cycle contingency reboost requirement.

There is a negative margin for the Shuttle manifest which will require weight reduction or utilization of reserve performance margins.

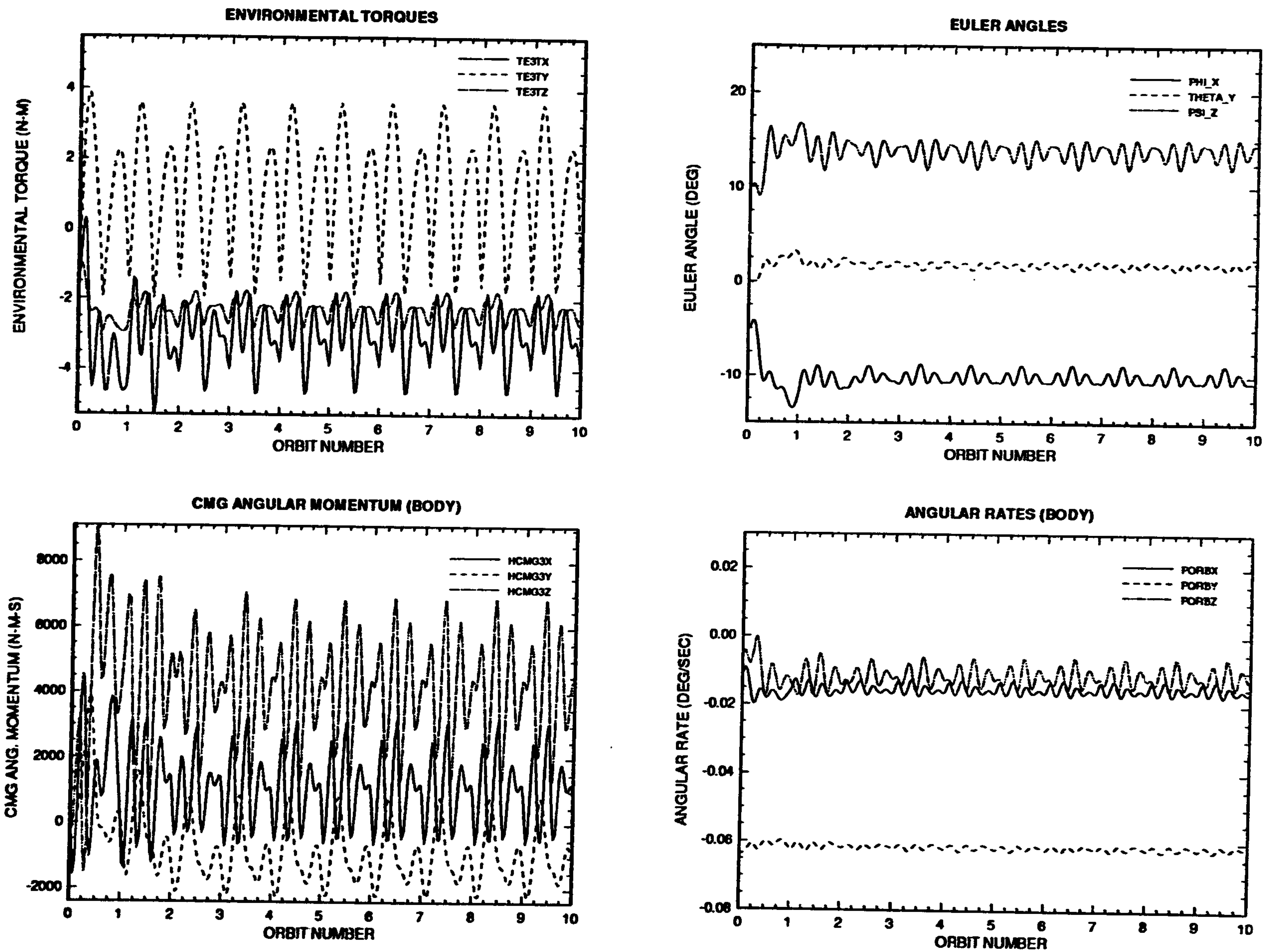


Figure 5.17.4-2 Stage 17 control plots without Shuttle attached.

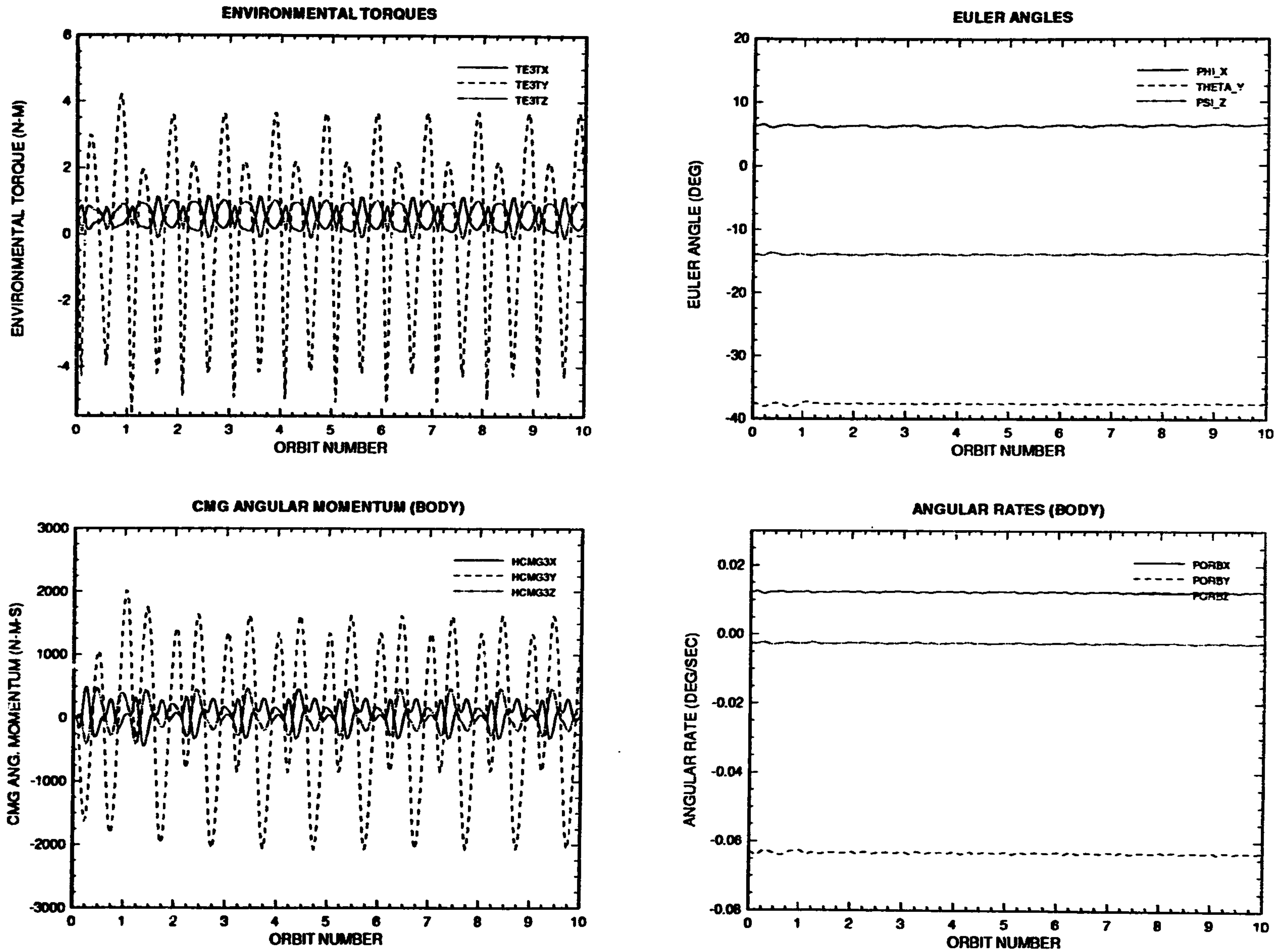


Figure 5.17.4-3 Stage 17 control plots with Shuttle attached.

5.18 Stage 18 Flight Characterization

5.18.1 Stage 18 - Flight 12A+ Shuttle Flight Manifest

This is an additional Shuttle flight over the baseline ISS 9/28/94 assembly sequence. Table 5.18.1-1 lists the Shuttle Flight Manifest for Stage 18 - Flight 12A+. The total mass of the station hardware to orbit is 6083 lbs, while the FSE is 9475 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 23399 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a mission flight margin of 7841 lbs.

5.18.2 Stage 18 Configuration

Figure 5.18.2-1 displays the isometric view of Stage 18 after the Shuttle departs and the scheduled assembly is completed. Figure 5.18.2-2 shows the front, side, top and isometric views of Stage 18 with the Shuttle attached.

5.18.3 Flight 12A+ Assembly Operations Description

Rendezvous of the Shuttle with the Stage 17 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 12A+ is a 15 day mission with 7 EVAs. EVA tasks that remain from flight 12A are completed during the first half of this flight. The primary purpose of those EVAs is to prepare for deployment of the P4 PV arrays, reconfigure the power distribution equipment following deployment of the P4 arrays, and activate the S1 and P1 thermal control system equipment. Upon completion of those tasks, the port P6 PV array and the stbd and aft ETCS radiators on P6 are stowed in preparation for relocation on a future flight. The SRMS unberths the P5 spacer truss and hands off the element to the SSRMS, which then attaches the P5 spacer to the P3/P4 truss elements. The P4/P5 MT/CETA rails are installed. The 2 additional battery sets delivered on this flight are installed on the P4 IEA using the SPDM.

Following separation, Stage 18 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 17 functionality, plus:

- P4 power module active - two additional power channels (6 batteries each)
- Full PV battery complement at P4
- Port P6 channel shut down
- S1 and P1 TCS active

Resources Available:	*Power:*	*28,200 W*	
	Thermal:	*TBD*	
	EVA:	*84 crew-hours*	
Resources Required:	*Power:*	*13,259 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		229 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*68:10 crew-hours*	

Table 5.18.1-1 Stage 18 - Flight 12A+ Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
P5	3528	
ULC		1540
DDC-B		735
P4 Battery Sets (2)	1868	
P4/P5 MT/CETA Rails	688	
16 -day EDO Pallet		7200
subtotal	**6083**	**9475**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-2770
Additional Attach Hardware 1	790	
Additional Attach Hardware 2	990	
Additional Attach Hardware 3	990	
	1780	
Variable Shuttle Consumables		-3582
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	495	
5th, 6th, 7th & 8th N2 tanks (@128 lbs/N2)	512	
5th Cryo Tank & Fluid	1575	
	3582	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-400
Total Shuttle Lift Capability		**23399**

Mission Flight Margin		**7841**

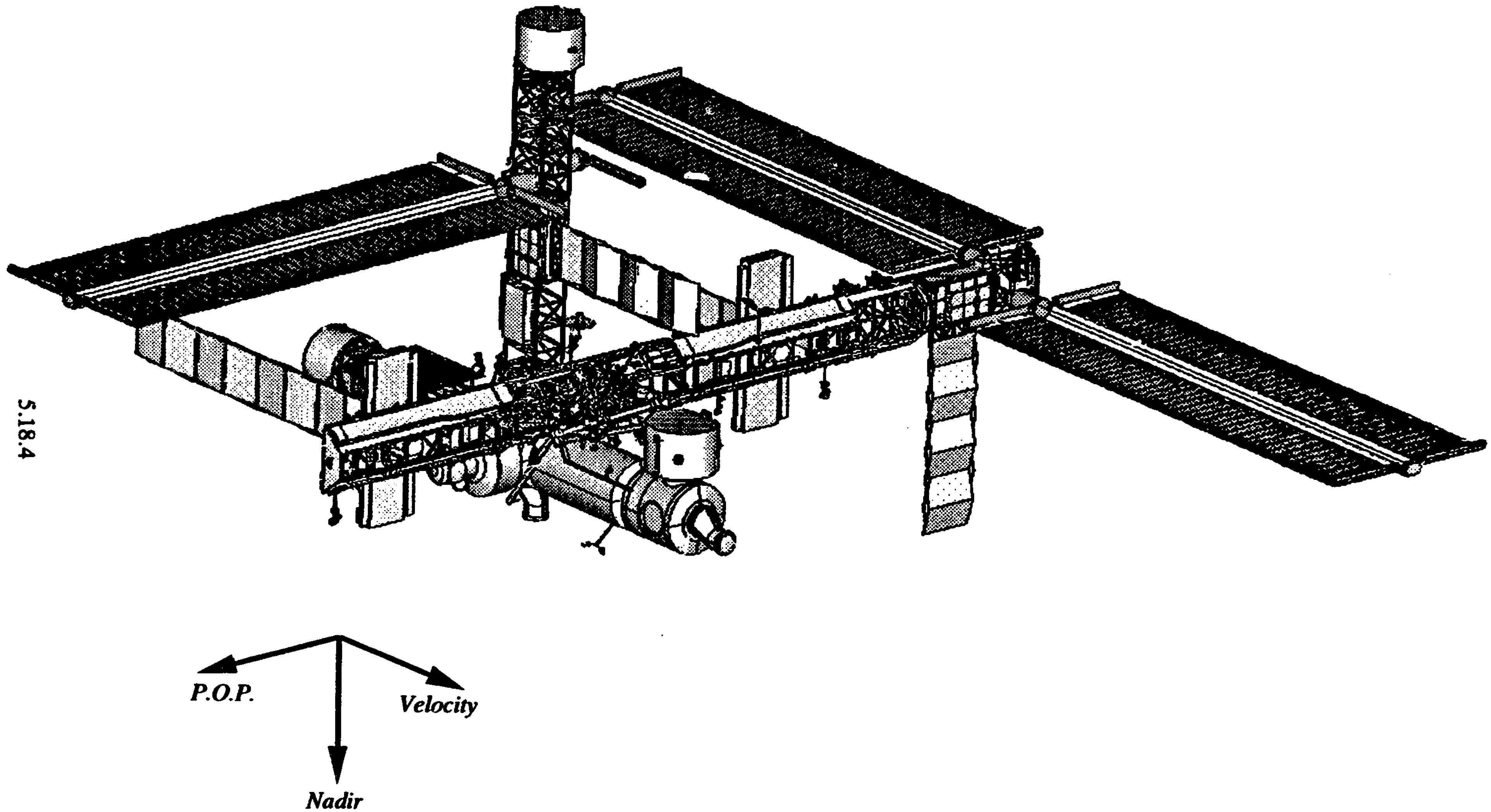


Figure 5.18.2-1 Stage 18 Configuration

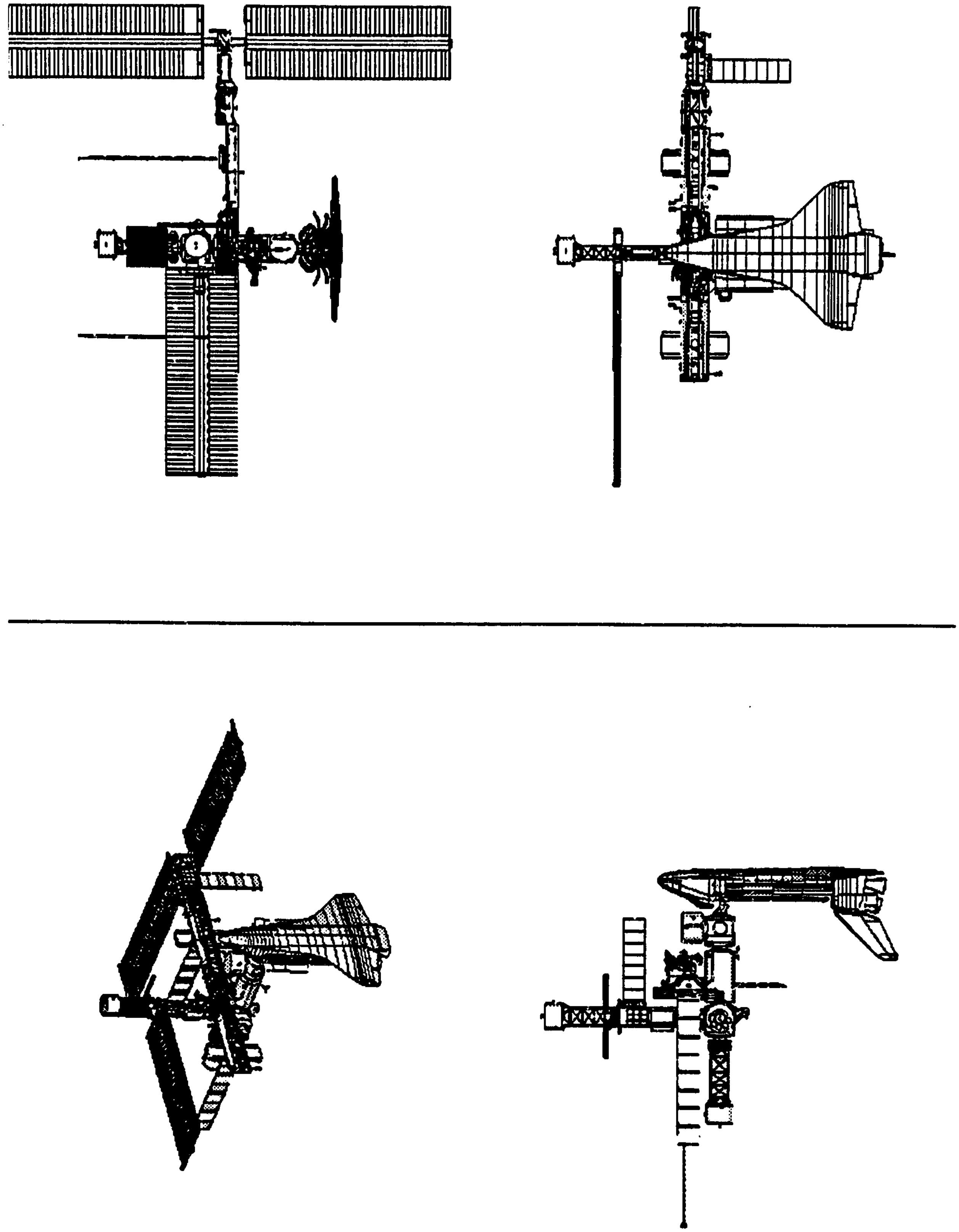


Figure 5.18.2-2 Stage 18 Configuration with Shuttle

5.18.4 Stage 18, Flight 12A+ Performance Characteristics

Stage 18, Flight 12A+ is assembled at a 230 n.mi. altitude in an LVLH flight mode with 2 double axis articulating PV arrays and one single axis PV array perpendicular to the orbit plane. The nominal launch date is December, 2000.

The Stage 18 steady state microgravity environment is depicted in figure 5.18.4-1. In a $+2\sigma$ atmosphere (solar flux = 212.0, geomagnetic index = 21.5) this stage has a flight attitude of yaw = 8.0, pitch = 0.0 , and roll = -2.3. Table 5.18.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given $+2\sigma$ atmosphere. This configuration does not provide a 1 μg environment to any of the racks.

Table 5.18.4-1 Stage 18 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.9
LAS-2	ISPR	1.9
LAS-3	ISPR	1.9
LAS-4	ISPR	1.9
LAS-5	SYS	1.9
LAS-6	SYS	1.9
LAF-1	SYS	2.4
LAF-2	SYS	2.4
LAF-3	SYS	2.4
LAF-4	SYS	2.4
LAF-5	SYS	2.4
LAF-6	SYS	2.4
LAP-1	ISPR	1.8
LAP-2	ISPR	1.8
LAP-3	ISPR	1.8
LAP-4	ISPR	1.8
LAP-5	SYS	1.8
LAP-6	SYS	1.8
LAC-1	ISPR	1.3
LAC-2	ISPR	1.3
LAC-3	ISPR	1.3
LAC-4	ISPR	1.3
LAC-5	ISPR	1.3
LAC-6	SYS	1.3

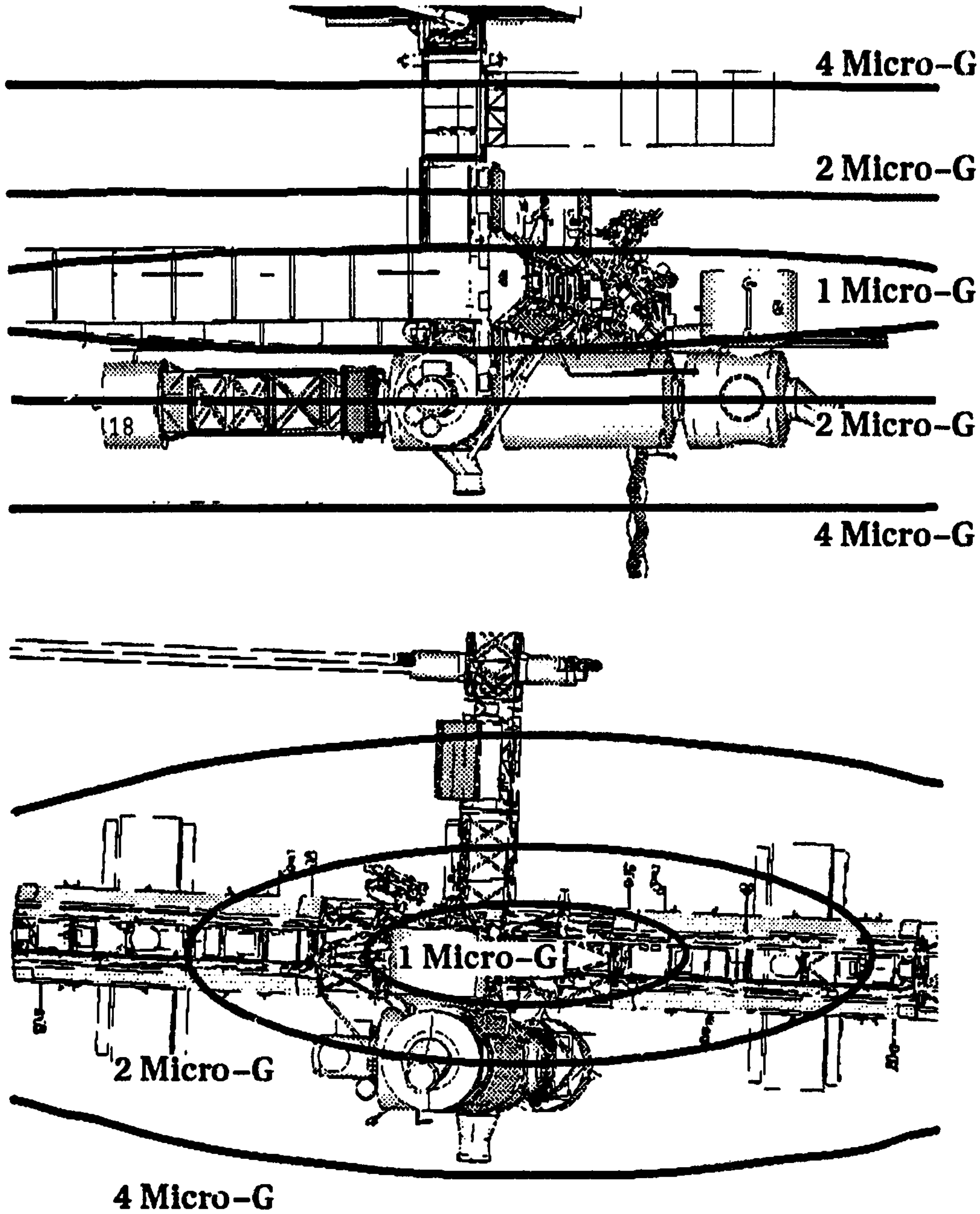


Figure 5.18.4-1 Stage 18 steady-state microgravity environment contours.

Table 5.18.4-2 summarizes the reboost lifetime characteristics of Stage 18 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 16.2 lbs/ft^2. There is insufficient propellant in either bus to perform the required reboost maneuver. The amount of propellant required to perform the reboost manuever was calculated as if using the aft bus, which has a reboost efficiency of 94%. For this stage there is insufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.18.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	239	1,464	-2,874	920	185

The control characteristics of stage 18 under design atmosphere conditions using the PDR yaw bias controller are displayed in figures 5.18.4-2. Table 5.18.4-3 summarizes the control characteristics depicted in the plots.

Table 5.18.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	4.0 degrees	-1.0 degrees	2.8 degrees	± 3.0 degrees	10,500 N-m-s
w/STS	18.6 degrees	-37.8 degrees	8.2 degrees	± 1.2 degrees	6600 N-m-s

The control characteristics of Stage 18 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller are displayed in figure 5.18.4-3. Table 5.18.4-3 summarizes the control characteristics depicted in the plots.

5.18.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

For this stage there is insufficient propellant reserve on the bus to meet the skip cycle contingency reboost requirement.

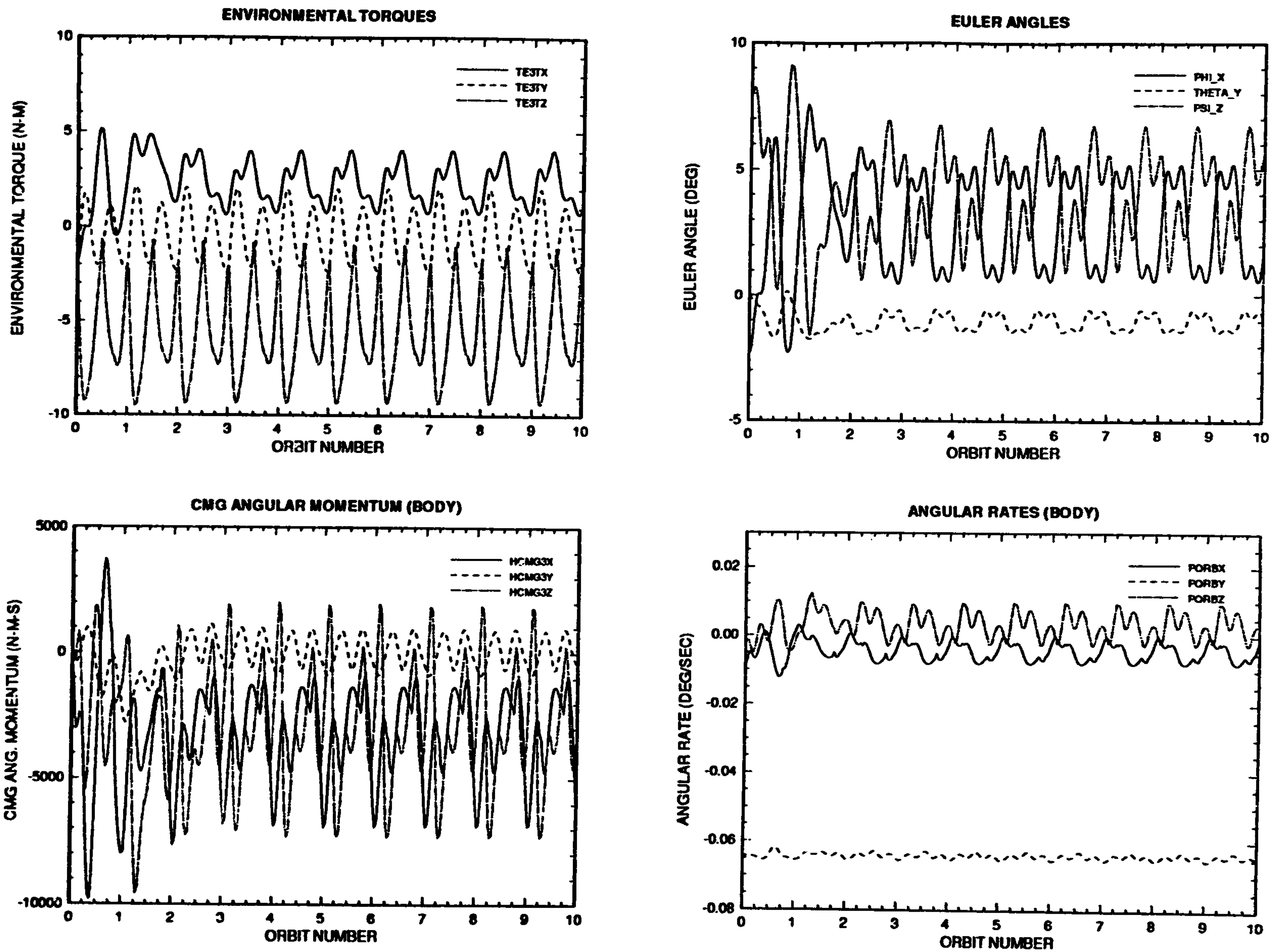


Figure 5.18.4-2 Stage 18 control plots without Shuttle attached.

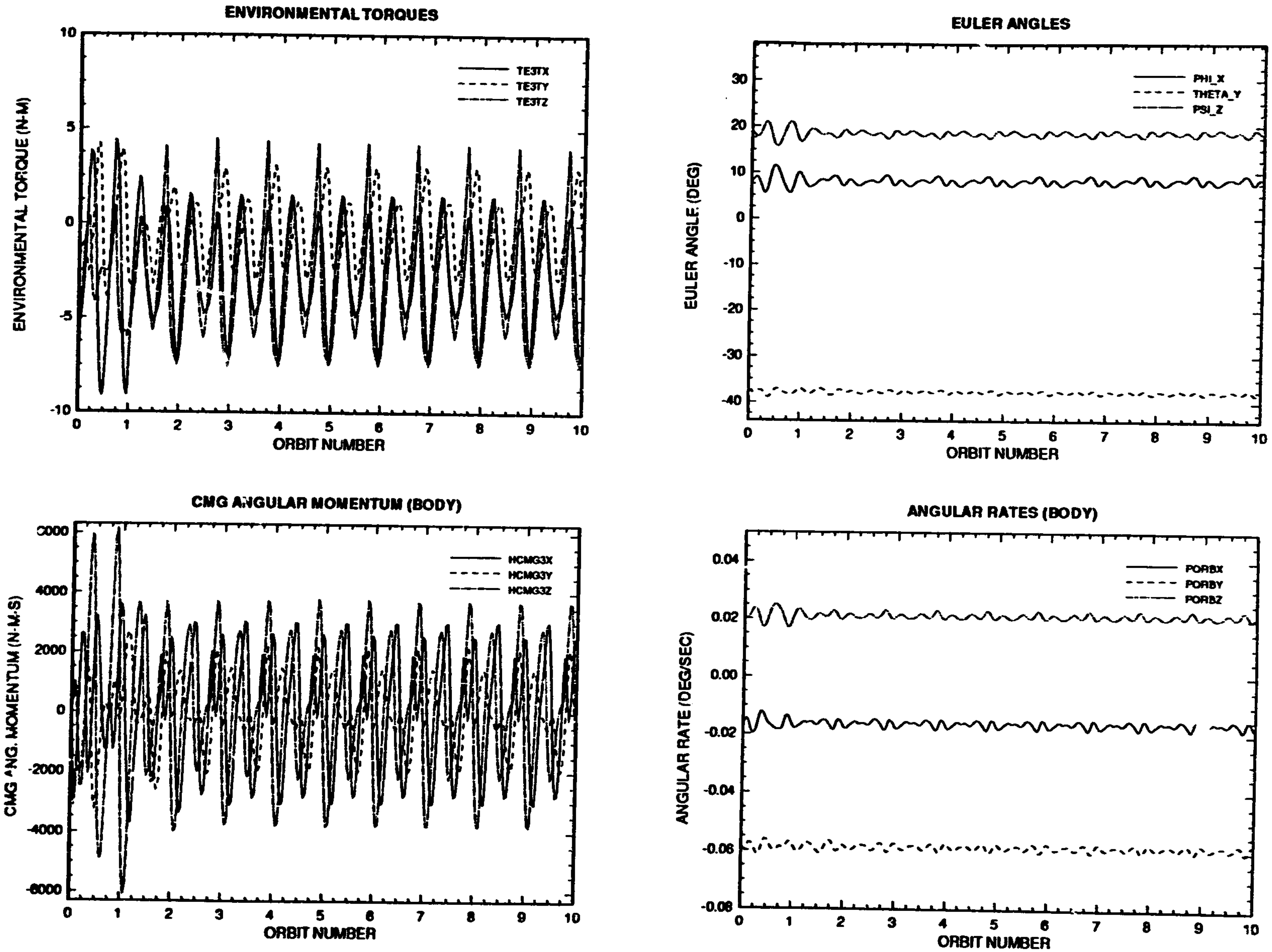


Figure 5.18.4-3 Stage 18 control plots with Shuttle attached.

5.19 Stage 19 Flight Characterization

5.19.1 Stage 19 - Flight UF-4 Shuttle Flight Manifest

The STS delivers the fourth utilization flight. Table 5.19.1-1 lists the Shuttle Flight Manifest for Stage 19 - Flight UF-4. The total mass of the station hardware to orbit is ~13000 lbs which is exchanged with TBD experiments already on-orbit. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 24646 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 941 lbs.

5.19.2 Stage 19 Configuration

Figure 5.19.2-1 displays the isometric view of Stage 19 after the Shuttle departs and the scheduled assembly is completed. Figure 5.19.2-2 shows the front, side, top and isometric views of Stage 19 with the Shuttle attached.

5.19.3 Flight UF-4 Assembly Operations Description

Rendezvous of the Shuttle with the Stage 18 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight UF-4 is a 12 day mission with 0 EVAs. The SRMS unberths the MPLM from the Shuttle payload bay and installs it on the Node 2 nadir port CBM. Upon completion of the rack exchange, the MPLM is returned to payload bay.

Following separation, Stage 19 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

<u>System Resource/Functionality</u>

Stage 18 functionality, plus:

- No additional functionality added on this flight

Resources Available:	*Power:*	*28,200 W*	
	Thermal:	*TBD*	
	EVA:	*0 crew-hours*	
Resources Required:	*Power:*	*13,259 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		229 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*0 crew-hours*	

Table 5.19.1-1 Stage 19 - Flight UF-4 Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
MPLM		10705
ISPRs	13000	
subtotal	**13000**	**10705**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-1324
APCU-i	714	
ROFU	450	
Misc hardware	160	
	1324	
Variable Shuttle Consumables		-3161
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	330	
5th & 6th N2 tanks (@128 lbs/N2)	256	
5th Cryo Tank & Fluid	1575	
	3161	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1150
Maintenance Reserve		-870
Total Shuttle Lift Capability		**24646**

Mission Flight Margin		**941**

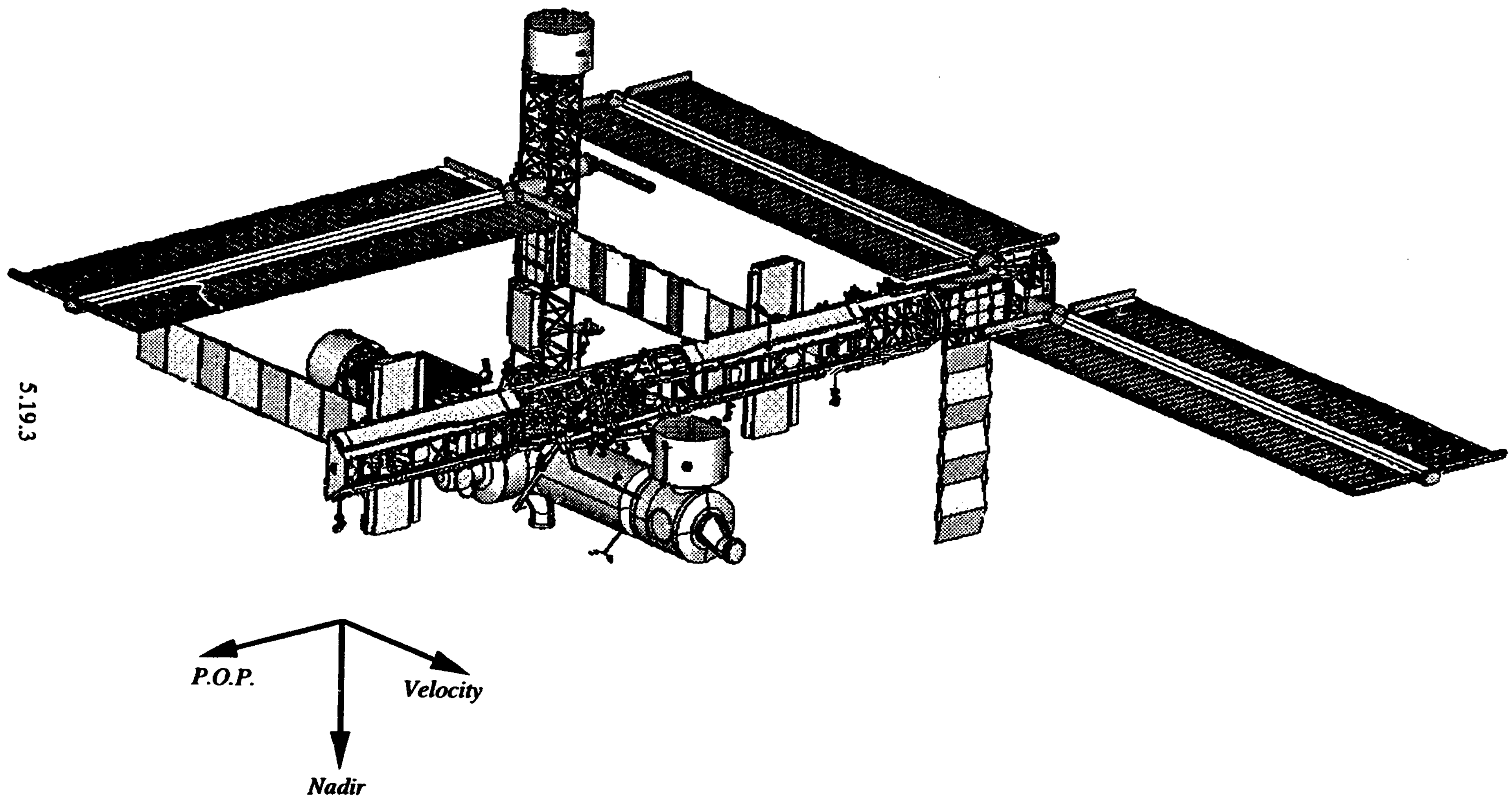


Figure 5.19.2-1 Stage 19 Configura: :n

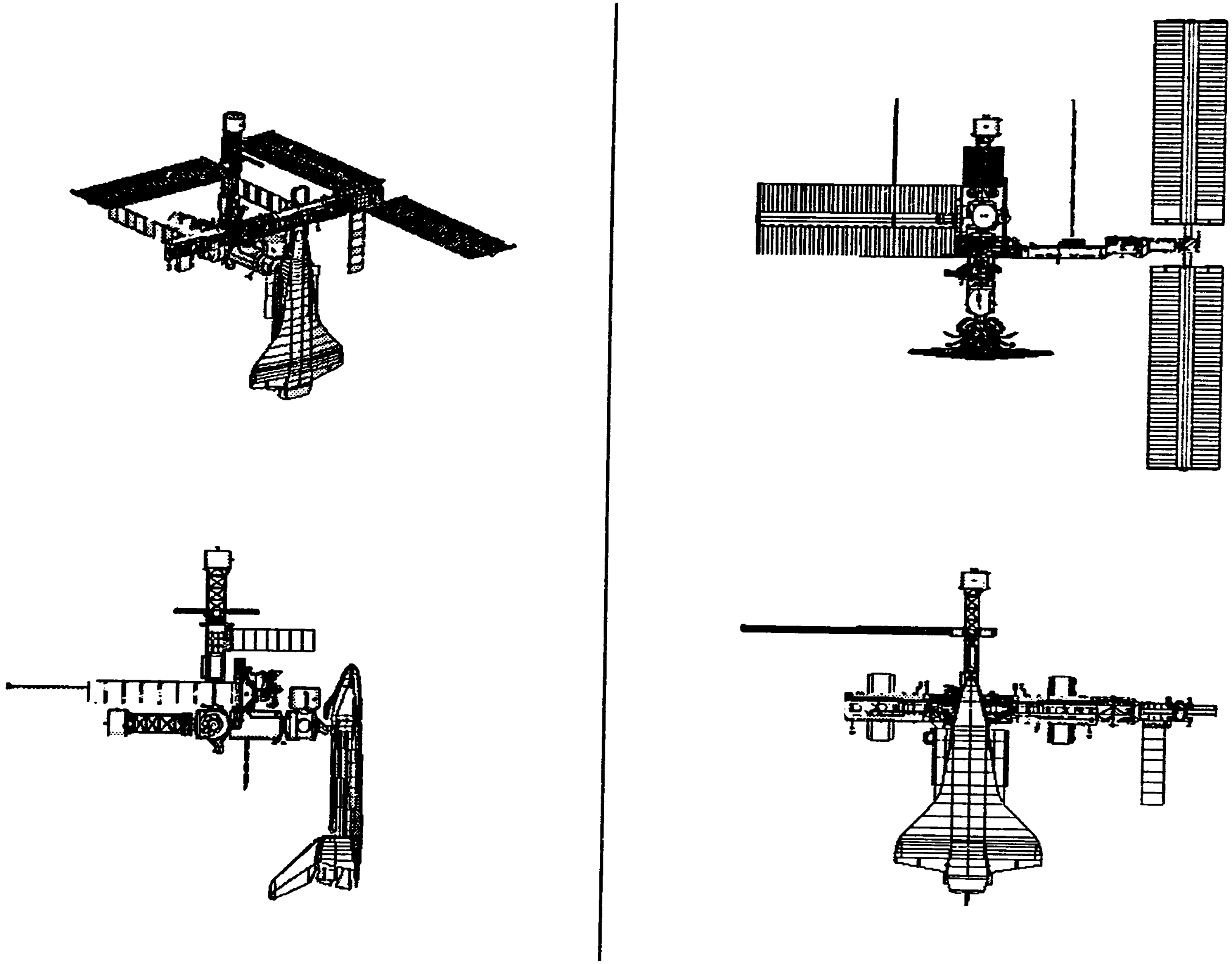


Figure 5.19.2-2 Stage 19 Configuration with Shuttle

5.19.4 Stage 19, Flight UF-4 Performance Characteristics

Stage 19, Flight UF-4 is assembled at a 230 n.mi. altitude in an LVLH flight mode with 2 double axis articulating PV arrays and one single axis PV array perpendicular to the orbit plane. The nominal launch date is February, 2001.

The Stage 19 steady state microgravity environment is depicted in figure 5.19.4-1. In a $+2\sigma$ atmosphere (solar flux = 204.0, geomagnetic index = 23.1) this stage has a flight attitude of yaw = 9.0, pitch = 0.0 , and roll = -2.0. Table 5.19.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given $+2\sigma$ atmosphere. This configuration does not provide a 1 μg environment to any of the racks.

Table 5.19.4-1 Stage 19 US Lab Racks Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.9
LAS-2	ISPR	1.9
LAS-3	ISPR	1.9
LAS-4	ISPR	1.9
LAS-5	SYS	1.9
LAS-6	SYS	1.9
LAF-1	SYS	2.4
LAF-2	SYS	2.4
LAF-3	SYS	2.4
LAF-4	SYS	2.4
LAF-5	SYS	2.4
LAF-6	SYS	2.4
LAP-1	ISPR	1.8
LAP-2	ISPR	1.8
LAP-3	ISPR	1.8
LAP-4	ISPR	1.8
LAP-5	SYS	1.8
LAP-6	SYS	1.8
LAC-1	ISPR	1.3
LAC-2	ISPR	1.3
LAC-3	ISPR	1.3
LAC-4	ISPR	1.3
LAC-5	ISPR	1.3
LAC-6	SYS	1.3

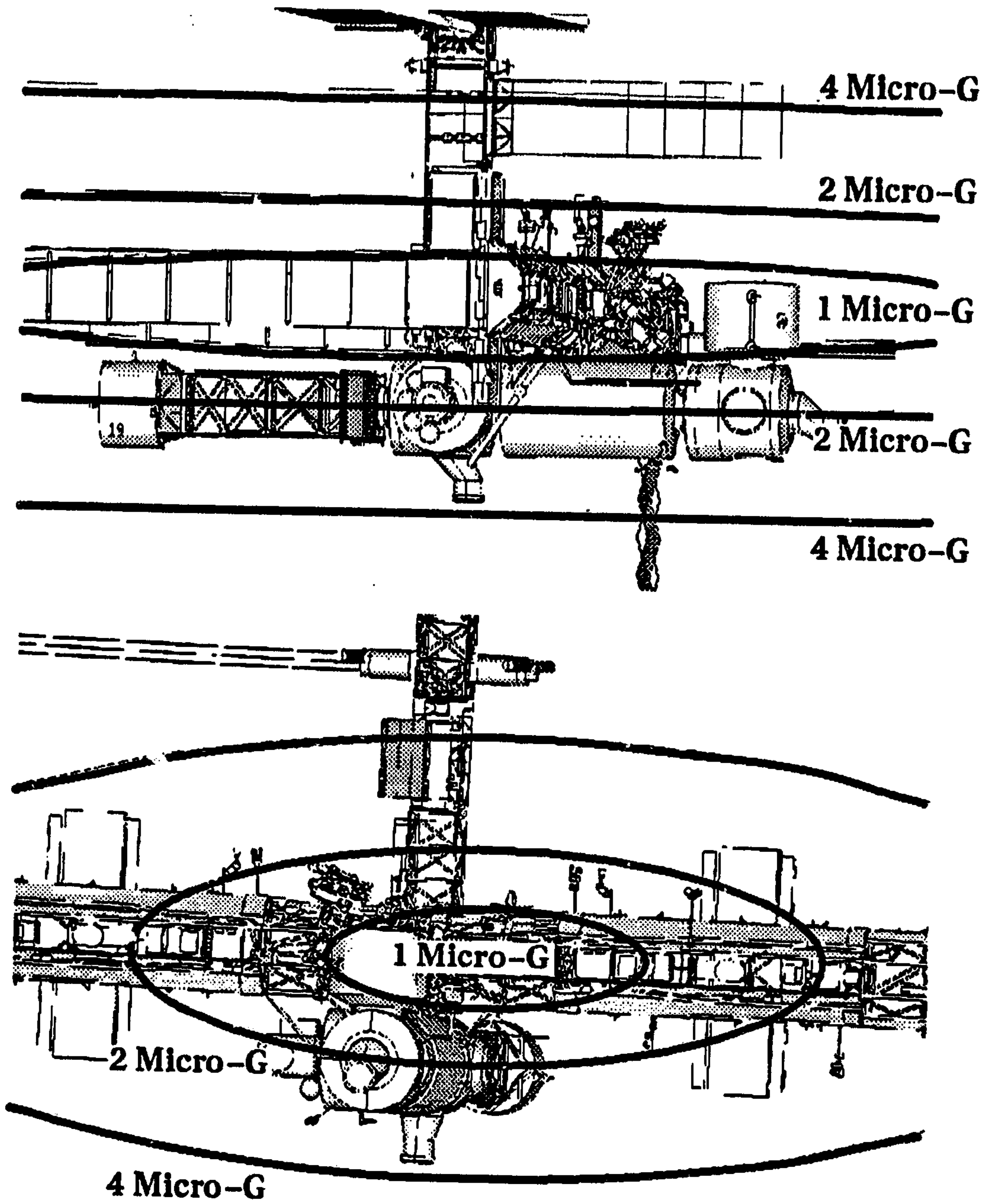


Figure 5.19.4-1 Stage 19 steady-state microgravity environment contours.

Table 5.19.4-2 summarizes the reboost lifetime characteristics of Stage 19 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 15.9 lbs/ft^2. There is insufficient propellant in either bus to perform the required reboost maneuver. The amount of propellant required to perform the reboost manuever was calculated using the aft bus, which currently has a reboost efficiency of 93%. For this stage there is insufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.19.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	239	1,486	-4,360	920	197

The control characteristics of Stage 19 under design atmosphere conditions using the PDR yaw bias controller are displayed in figure 5.19.4-2. Table 5.19.4-3 summarizes the control characteristics depicted in the plots.

Table 5.19.4-3 Stage UF-4 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	5.7 degrees	-1.0 degrees	1.5 degrees	± 3.2 degrees	9300 N-m-s
w/STS	0.0 degrees	-38.3 degrees	0.0 degrees	± 1.7 degrees	20,400 N-m-s

Neither PDR or CDR CMG attitude control algorithms were able to control the station attitude with the Shuttle attached using the available 18,980 N-m-s momentum capacity, even considering a 10,000 N-m-s momentum wheel augmentation. The control characteristics are shown in figure 5.19.4-4. Note that none of the individual components of the angular momentum requirement exceed CMG capacity.

5.19.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

For this stage there is insufficient propellant reserve on the bus to meet the skip cycle contingency reboost requirement.

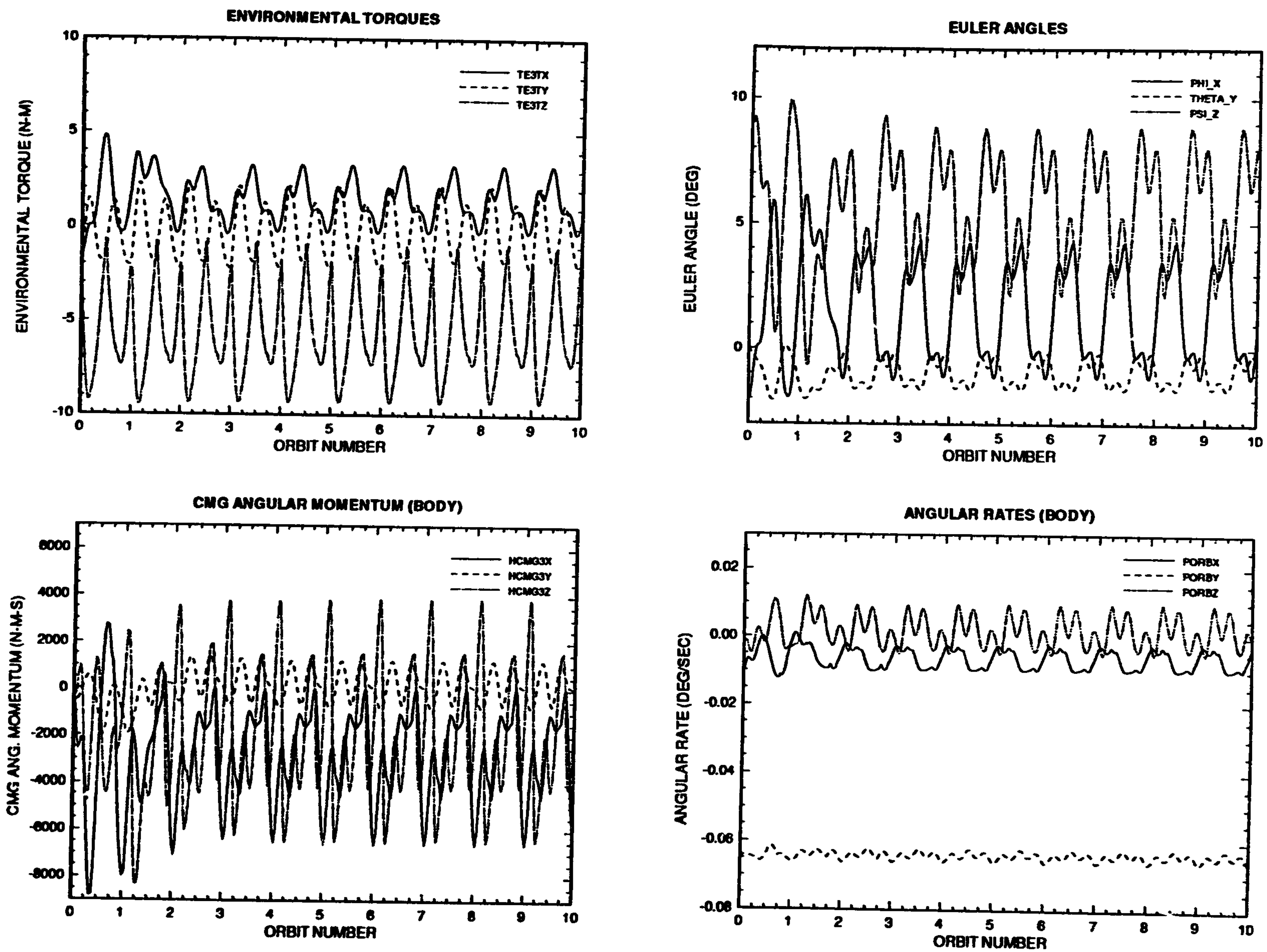


Figure 5.19.4-2 Stage 19 control plots without Shuttle attached.

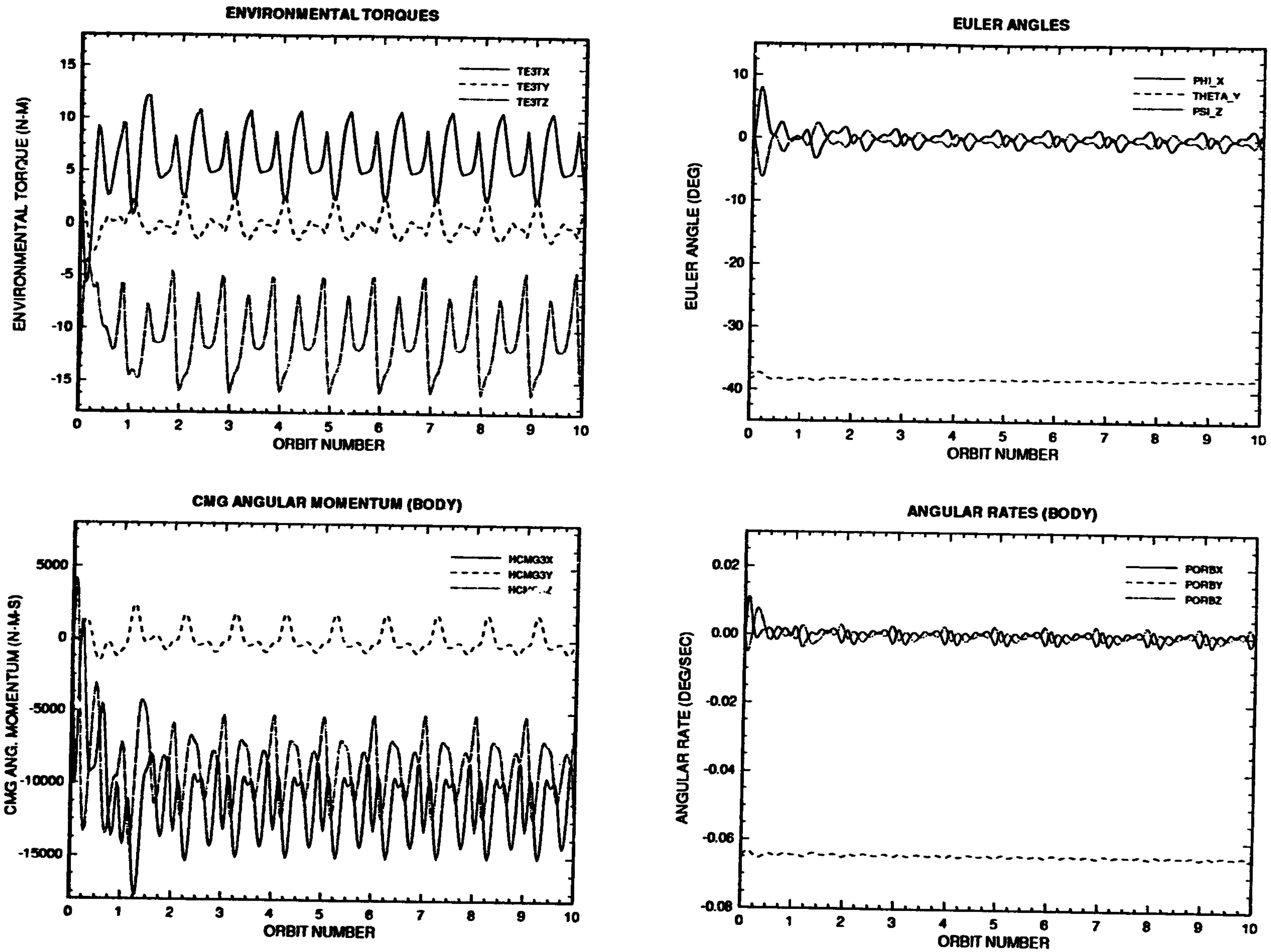


Figure 5.19.4-3 Stage 19 control plots with Shuttle attached.

5.20 Stage 20 Flight Characterization

5.20.1 Stage 20 - Flight BF-1 Shuttle Flight Manifest

Stage 20 is the first Bus-1 resupply flight for the station. Table 5.20.1-1 lists the Shuttle Flight Manifest for Stage 20 - Flight BF-1. The total mass of the station hardware to orbit is 25000 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 29458 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 4958 lbs.

5.20.2 Stage 20 Configuration

Figure 5.20.2-1 displays the isometric view of Stage 20 after the Shuttle departs and the scheduled assembly is completed. Figure 5.20.2-2 shows the front, side, top and isometric views of Stage 20 with the Shuttle attached.

5.20.3 Flight BF-1 Assembly Operations Description

Rendezvous of the Shuttle with the Stage 19 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight BF-1 is a 7 day mission with 0 EVAs. The purpose of this flight is to replace the Bus-1 which is attached to the stinger located on Node 1 (the "aft" Bus-1). The SSRMS is repositioned on the stinger grapple fixture. The SSRMS then grapples the Bus-1 and hands it to the SRMS. The SSRMS remains in this position while the SRMS places the spent bus in the Shuttle cargo bay and grapples the replacement Bus-1. The Bus-1 is then handed back to the SSRMS and installed on the stinger.

Following separation, Stage 20 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

<u>System Resource/Functionality</u>

Stage 19 functionality, plus:

- Bus-1 swapped to ensure adequate fuel supply

Resources Available:	*Power:*	*28,200 W*	
	Thermal:	*TBD*	
	EVA:	*0 crew-hours*	
Resources Required:	*Power:*	*13,259 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		229 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*0 crew-hours*	

Table 5.20.1-1 Stage 20 - Flight BF-2 Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
Bus-1	25000	
subtotal	**25000**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-238
Variable Shuttle Consumables		-55
Food & Gear (-55 lbs/day over 6)	55	
	55	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-400
Total Shuttle Lift Capability		**29958**

Mission Flight Margin		**4958**

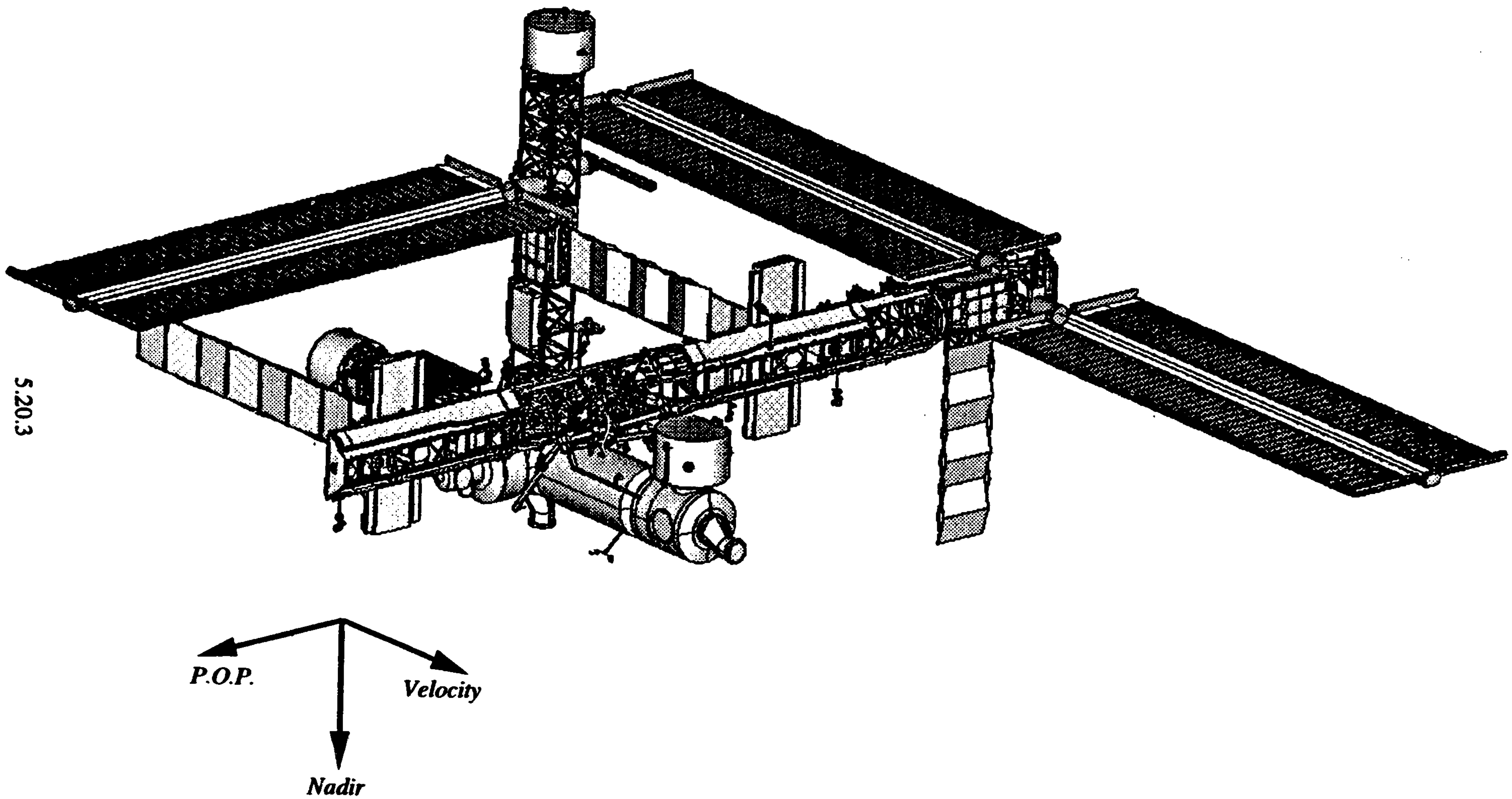


Figure 5.20.2–1 Stage 20 Configuration

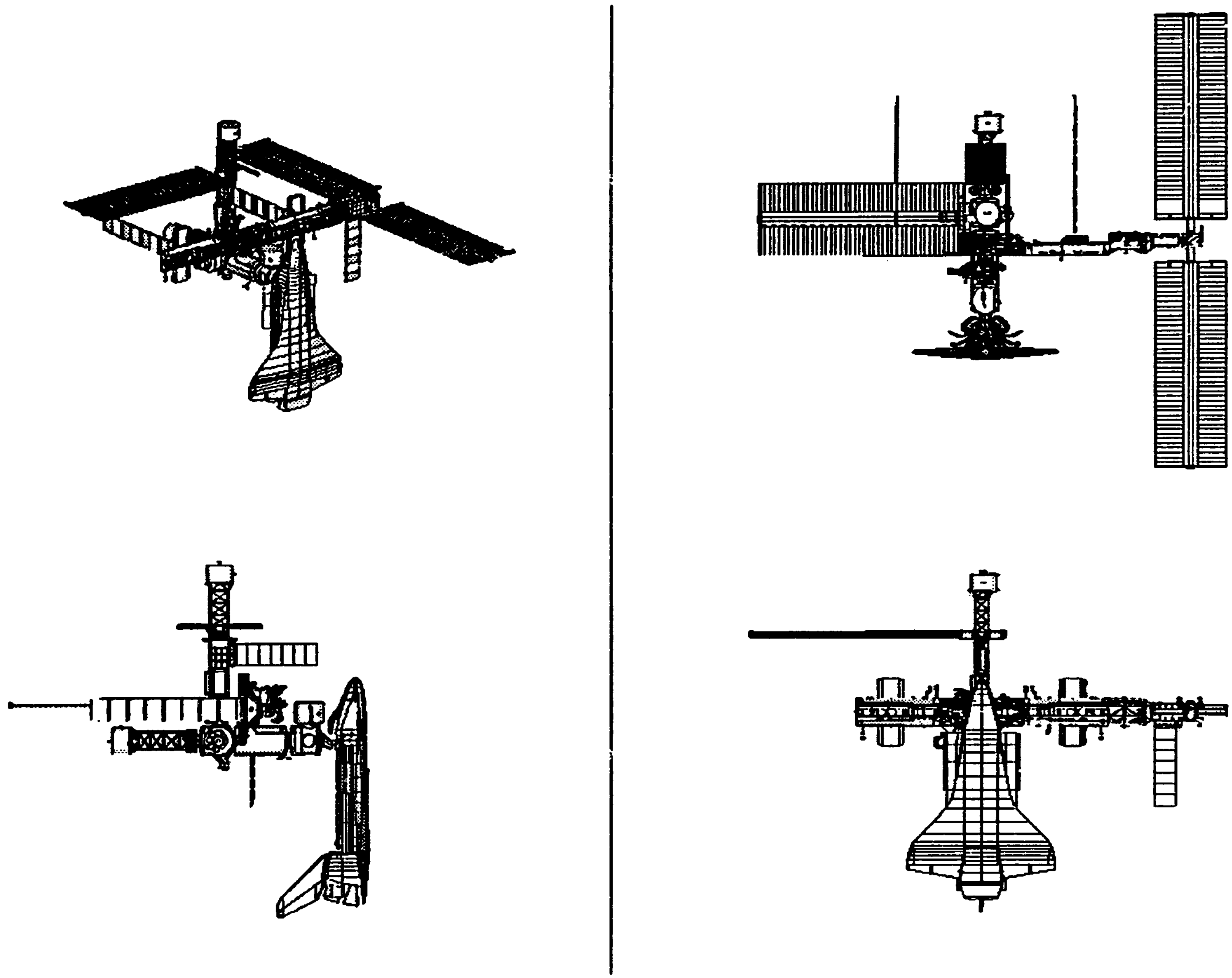


Figure 5.20.2-2 Stage 20 Configuration with Shuttle

5.20.4 Stage 20, Bus Flight 1 Performance Characteristics

Stage 20, Flight BF-1 is assembled at a 230 n.mi. altitude in an LVLH flight mode with 2 double axis articulating PV arrays and one single axis PV array perpendicular to the orbit plane. The nominal launch date is April, 2001.

The Stage 20 steady state microgravity environment is depicted in figure 5.20.4-1. In a +2σ atmosphere (solar flux = 200.4, geomagnetic index = 23.4) this stage has a flight attitude of yaw = 9.0, pitch = 0.0 , and roll = -2.0. Table 5.20.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration does not provide a 1 μg environment to any of the racks.

Table 5.20.4-1 Stage 20 US Lab Racks Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.9
LAS-2	ISPR	1.9
LAS-3	ISPR	1.9
LAS-4	ISPR	1.9
LAS-5	SYS	1.9
LAS-6	SYS	1.9
LAF-1	SYS	2.4
LAF-2	SYS	2.4
LAF-3	SYS	2.4
LAF-4	SYS	2.4
LAF-5	SYS	2.4
LAF-6	SYS	2.4
LAP-1	ISPR	1.8
LAP-2	ISPR	1.8
LAP-3	ISPR	1.8
LAP-4	ISPR	1.8
LAP-5	SYS	1.8
LAP-6	SYS	1.8
LAC-1	ISPR	1.3
LAC-2	ISPR	1.3
LAC-3	ISPR	1.3
LAC-4	ISPR	1.3
LAC-5	ISPR	1.3
LAC-6	SYS	1.3

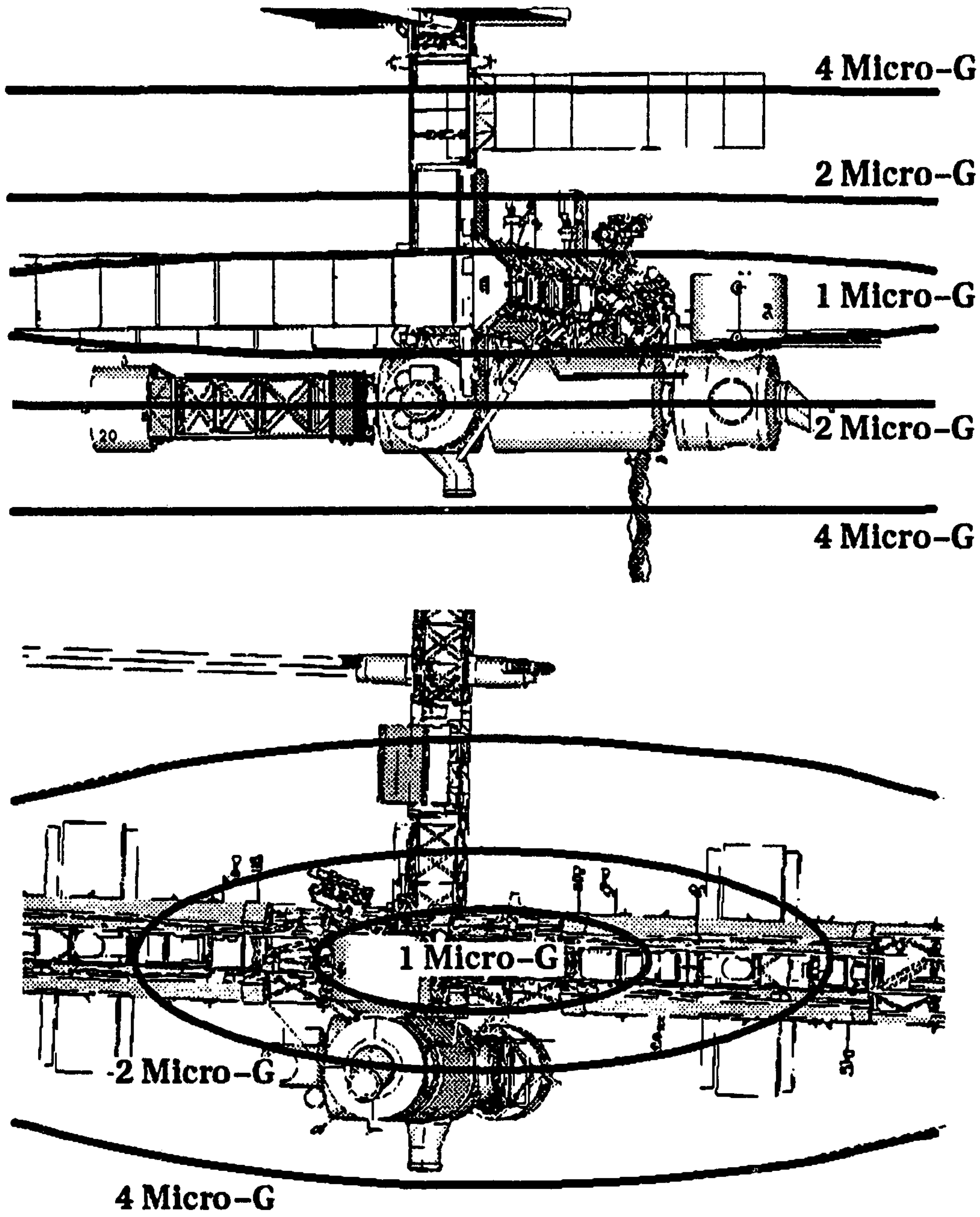


Figure 5.20.4-1 Stage 20 steady-state microgravity environment contours.

Table 5.20.4-2 summarizes the reboost lifetime characteristics of Stage 20 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 15.9 lbs/ft^2. The reboost is performed using the aft bus which currently has a reboost efficiency of 93%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.20.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	239	1,542	10,058	920	209

Since the Stage 20 mass and configuration characteristics are the same as Stage 19 please refer to Section 5.19.4 for the appropriate control results.

5.20.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

5.21 Stage 21 Flight Characterization

5.21.1 Stage 21 - Flight 13A Shuttle Flight Manifest

The STS delivers the starboard S3/S4 segment. Table 5.21.1-1 lists the Shuttle Flight Manifest for Stage 21 - Flight 13A. The total mass of the station hardware to orbit is 31994 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 30845 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a negative mission flight margin of -1149 lbs.

5.21.2 Stage 21 Configuration

Figure 5.21.2-1 displays the isometric view of Stage 21 after the Shuttle departs and the scheduled assembly is completed. Figure 5.21.2-2 shows the front, side, top and isometric views of Stage 21 with the Shuttle attached.

5.21.3 Flight 13A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 20 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 13A is an 8 day mission with 2 EVAs. The SRMS unberths the S3/S4 ITS from the Shuttle payload bay and hands off to the SSRMS which installs the element on S1 ITS. Due to the EVA time constraint on this flight, no EPS preparation or activation occurs until the following flight. The final EVA involves the relocation of the P6 stbd ETCS radiator to the S4 PV module where it will function as the S4 PV radiator.

Following separation, Stage 21 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

<u>System Resource/Functionality</u>

Stage 20 functionality, plus:

- S3 ITS and S4 power module delivered to orbit (partially installed, not activated)

Resources Available:	*Power:*	*28,200 W*	
	Thermal:	*TBD*	
	EVA:	*24 crew-hours*	
Resources Required:	*Power:*	*13,259 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		229 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*16:20 crew-hours*	

Table 5.21.1-1 Stage 21 - Flight 13A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
S3 TRUSS SEGMENT	4410	
S3 UTILITY TRAYS	1417	
SARJ STATOR	920	
SARJ UTA	920	
4 Payload Attach Structures (PAS)	1376	
S4 TRUSS SEGMENT	9482	
BG DEPLOYED	1338	
S3/S4 BARS	463	
IEA BATTERIES (4 sets)	4968	
S3 ROTARY ASSY	0	
S3 ROTARY BULKHEAD	491	
SARJ ROTOR	920	
SIA PVA DEPLOYED	2646	
SIF PVA DEPLOYED	2646	
subtotal	**31994**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi)		-1000
Additional Shuttle Performance Enhancements		1500
Variable Integrated Hardware		-238
Variable Shuttle Consumables		-238
Food & Gear (-55 lbs/day over 6)	110	
5th N2 tanks (@128 lbs/N2)	128	
	238	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-330
Total Shuttle Lift Capability		**30845**
Mission Flight Margin		**-1149**

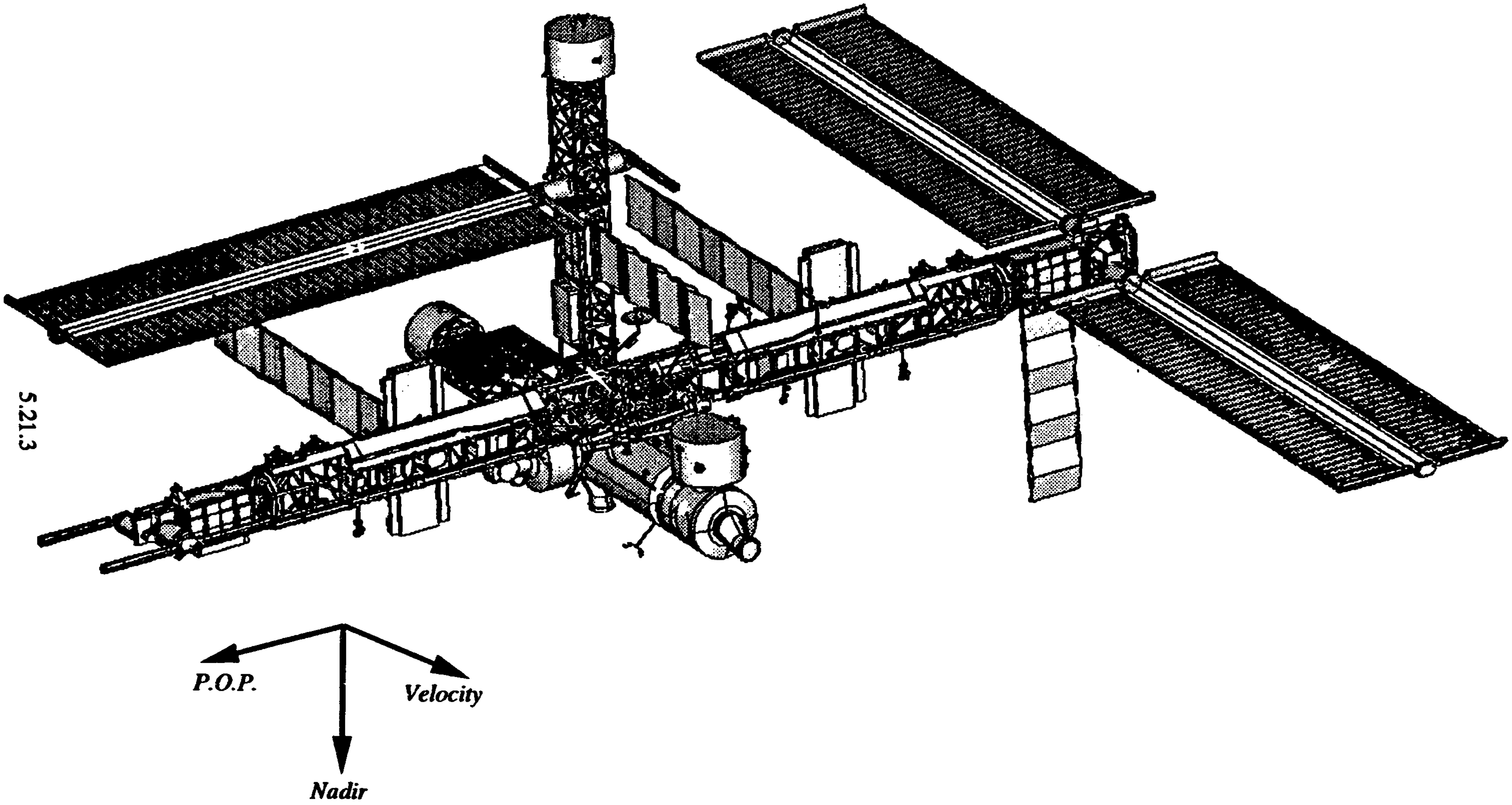


Figure 5.21.2-1 Stage 21 Configuration

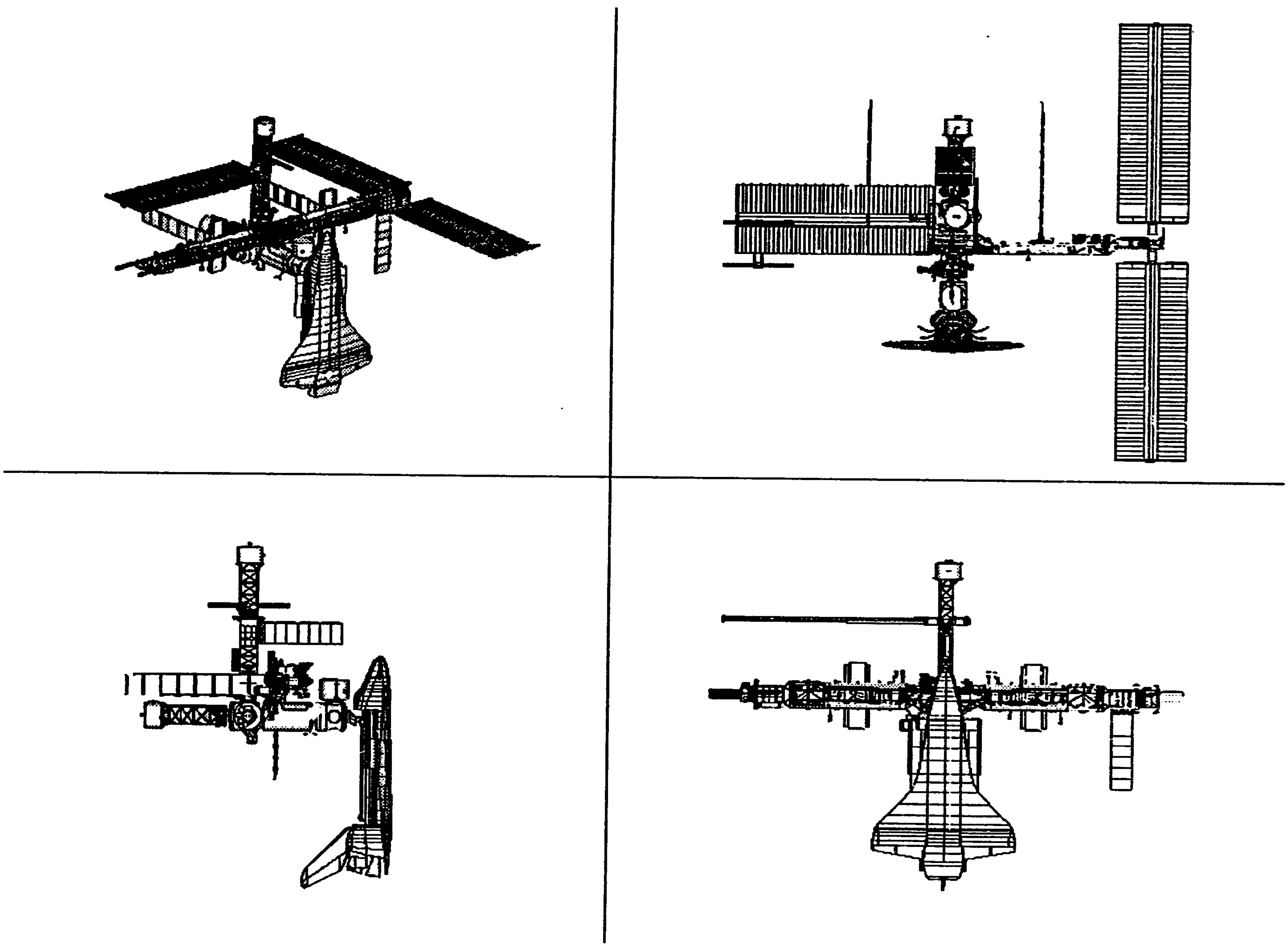


Figure 5.21.2-2 Stage 21 Configuration with Shuttle

5.21.4 Stage 21, Flight 13A Performance Characteristics

Stage 21, Flight 13A is assembled at a 230 n.mi. altitude in an LVLH flight mode with with 2 double axis articulating PV arrays and one single axis PV array perpendicular to the orbit plane. The nominal launch date is June, 2001.

Stage 21 in a $+2\sigma$ atmosphere (solar flux = 195.7, geomagnetic index = 23.1) has a flight attitude of yaw = 0.0, pitch = 2.4 , and roll = 0.0. The steady state microgravity environment is depicted in figure 5.21.4-1. Table 5.21.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given $+2\sigma$ atmosphere. This configuration does not provide a 1 μg environment to any of the racks.

Table 5.21.4-1 Stage 21 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.9
LAS-2	ISPR	1.9
LAS-3	ISPR	1.9
LAS-4	ISPR	1.9
LAS-5	SYS	1.9
LAS-6	SYS	2.0
LAF-1	SYS	2.5
LAF-2	SYS	2.5
LAF-3	SYS	2.6
LAF-4	SYS	2.6
LAF-5	SYS	2.6
LAF-6	SYS	2.6
LAP-1	ISPR	1.9
LAP-2	ISPR	1.9
LAP-3	ISPR	1.9
LAP-4	ISPR	1.9
LAP-5	SYS	1.9
LAP-6	SYS	2.0
LAC-1	ISPR	1.2
LAC-2	ISPR	1.2
LAC-3	ISPR	1.2
LAC-4	ISPR	1.2
LAC-5	ISPR	1.3
LAC-6	SYS	1.3

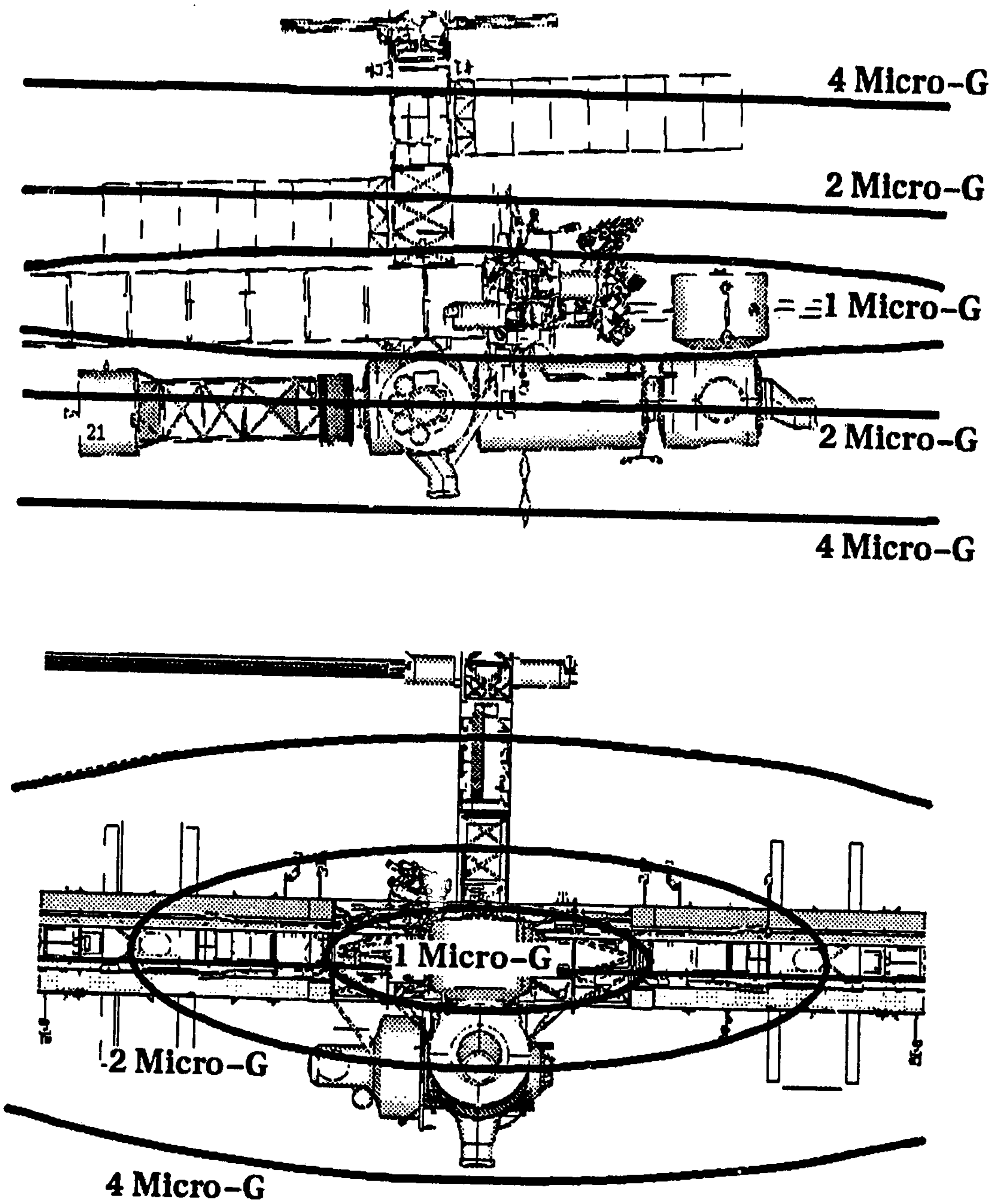


Figure 5.21.4-1 Stage 21 steady-state microgravity environment contours.

Table 5.21.4-2 summarizes the reboost lifetime characteristics of Stage 21 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 18.6 lbs/ft^2. The reboost is performed using the aft bus which currently has a reboost efficiency of 94%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.21.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	237	1,189	8,869	920	218

The control characteristics of Stage 21 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.21.4-2. Table 5.21.4-3 summarizes the control characteristics depicted in the plots.

Table 5.21.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	0.0 degrees	-5.3 degrees	0.0 degrees	±1.2 degrees	14,700 N-m-s
w/STS	9.1 degrees	-38.1 degrees	0.4 degrees	± 3.5 degrees	14,500 N-m-s

The control characteristics of Stage 21 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.21.4-3. Table 5.21.4-3 summarizes the control characteristics depicted in the plots.

5.21.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

There is a negative weight margin for the Shuttle manifest which will require weight reduction or utilization of reserve performance margins.

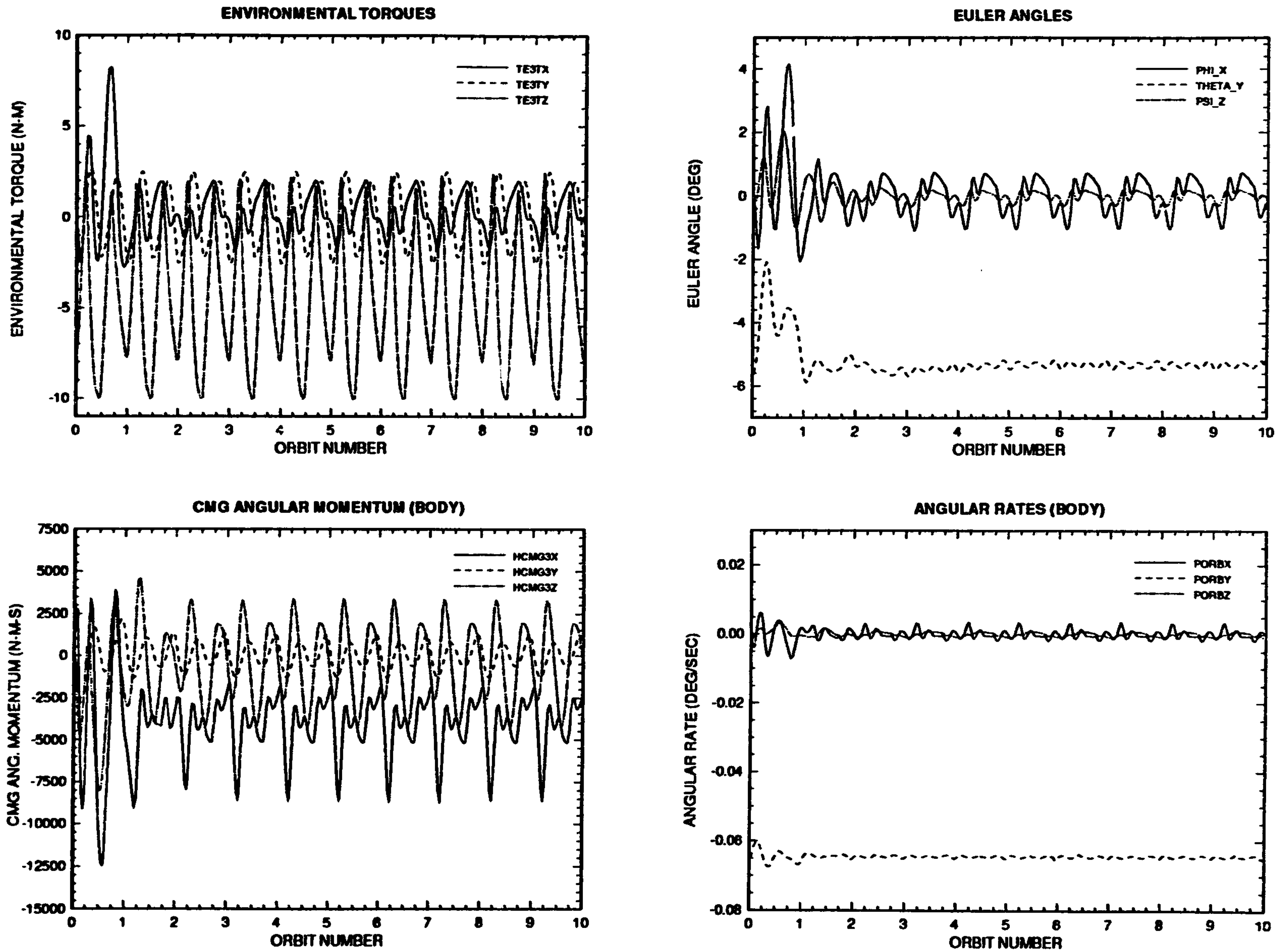


Figure 5.21.4-2 Stage 21 control plots without Shuttle attached.

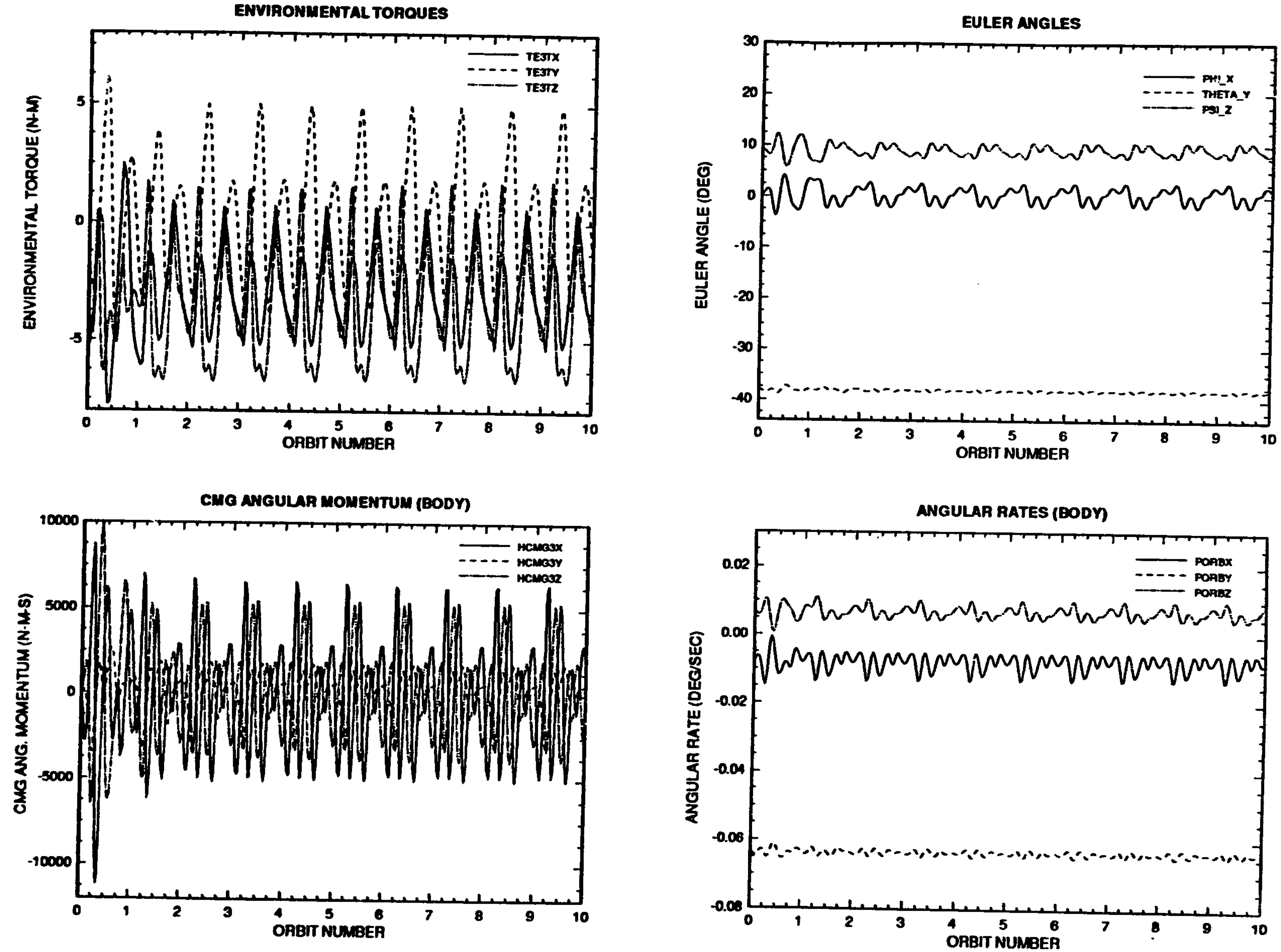


Figure 5.21.4-3 Stage control plots with Shuttle attached.

5.22 Stage 22 Flight Characterization

5.22.1 Stage 22 - Flight 13A+ Shuttle Flight Manifest

Stage 22 is an additional shuttle flight over that in the 9/28/94 Baseline ISSA Assembly Sequence. The STS delivers 2 PV battery sets and the S4 & P6 MT/CETA rails on an Unpressurized Logistics Carrier (ULC). Table 5.22.1-1 lists the Shuttle Flight Manifest for Stage 22 - Flight 13A+. The total mass of the station hardware to orbit is 2556 lbs. The second section of the table shows the Shuttle Performance and hardware/ consumables required for the mission resulting in the net Shuttle Lift Capability of 25249 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 11,018 lbs.

5.22.2 Stage 22 Configuration

Figure 5.22.2-1 displays the isometric view of Stage 22 after the Shuttle departs and the scheduled assembly is completed. Figure 5.22.2-2 shows the front, side, top and isometric views of Stage 22 with the Shuttle attached.

5.22.3 Flight 13A+ Assembly Operations Description

Rendezvous of the Shuttle with the Stage 21 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 13A+ is a 15 day mission with 7 EVAs. EVA tasks that remain from flight 13A are completed during the first half of this flight. The primary purpose of those EVAs is to prepare for deployment of the S4 PV arrays, and reconfigure the power distribution equipment following deployment of the S4 PV arrays. Upon completion of those tasks, the starboard P6 PV array and the P6 PV radiator are stowed in preparation for relocation during this flight. The SSRMS unberths the Bus-1/stinger element (zenith) from the top of the P6 segment, hands it to the SRMS which holds the element in a location that provides a clear area for the P6 relocation. The SSRMS unberths the P6 power module from the Z1 truss and then attaches the element to the P3/P4 truss segment. Following re-installation of the P6 segment, the SSRMS retrieves the Bus-1/stinger from the SRMS and berths it to the zenith surface of the Z1 truss (see figure 5.22.3-1 for a graphical depiction of these operation). The P6 PV arrays and PV radiator are deployed and re-activated. The S4/P6 MT/CETA rails are installed. The 2 PV battery sets delivered on this flight are installed on the S4 IEA using the SPDM.

Following separation, Stage 22 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 21 functionality, plus:

- S4 power module active - 2 Additional EPS Channels (6 batteries each)
- Full PV battery complement at S4
- Reactivated EPS Channel on P6 (4 batteries on each channel)
- ITS P6 in permanent port-outboard location
- 4 additional EATC radiators deployed and 4 activated (all EATC radiators now activated)

Resources Available:	*Power:*	*47,200 W*	
	Thermal:	*TBD*	
	EVA:	*72 crew-hours*	
Resources Required:	*Power:*	*13,392 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		229 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*63:40 crew-hours*	

Table 5.22.1-1 Stage 22 - Flight 13A+ Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
ULC		2935
DDC-B		1540
PV battery sets (2)	1868	
MT/CETA rails (S4 & P6)	688	
16-day EDO Pallet		7200
subtotal	**2556**	**11675**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-990
Additional Attach Hardware	990	
	990	
Variable Shuttle Consumables		-3582
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	495	
5th, 6th, 7th & 8th N2 tanks (@128 lbs/N2)	512	
5th Cryo Tank & Fluid	1575	
	3582	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-330
Total Shuttle Lift Capability		**25249**

Mission Flight Margin		**11018**

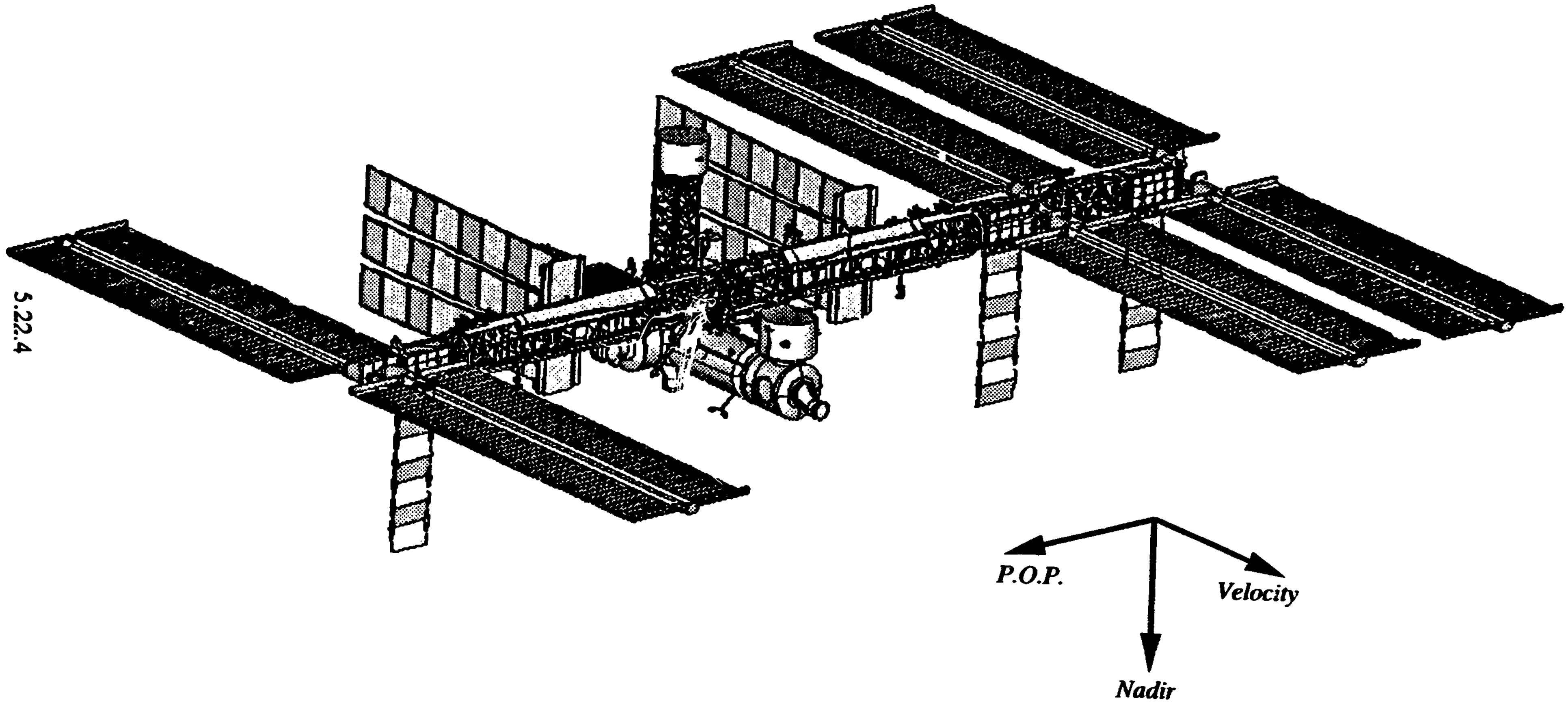


Figure 5.22.2–1 Stage 22 Configuration

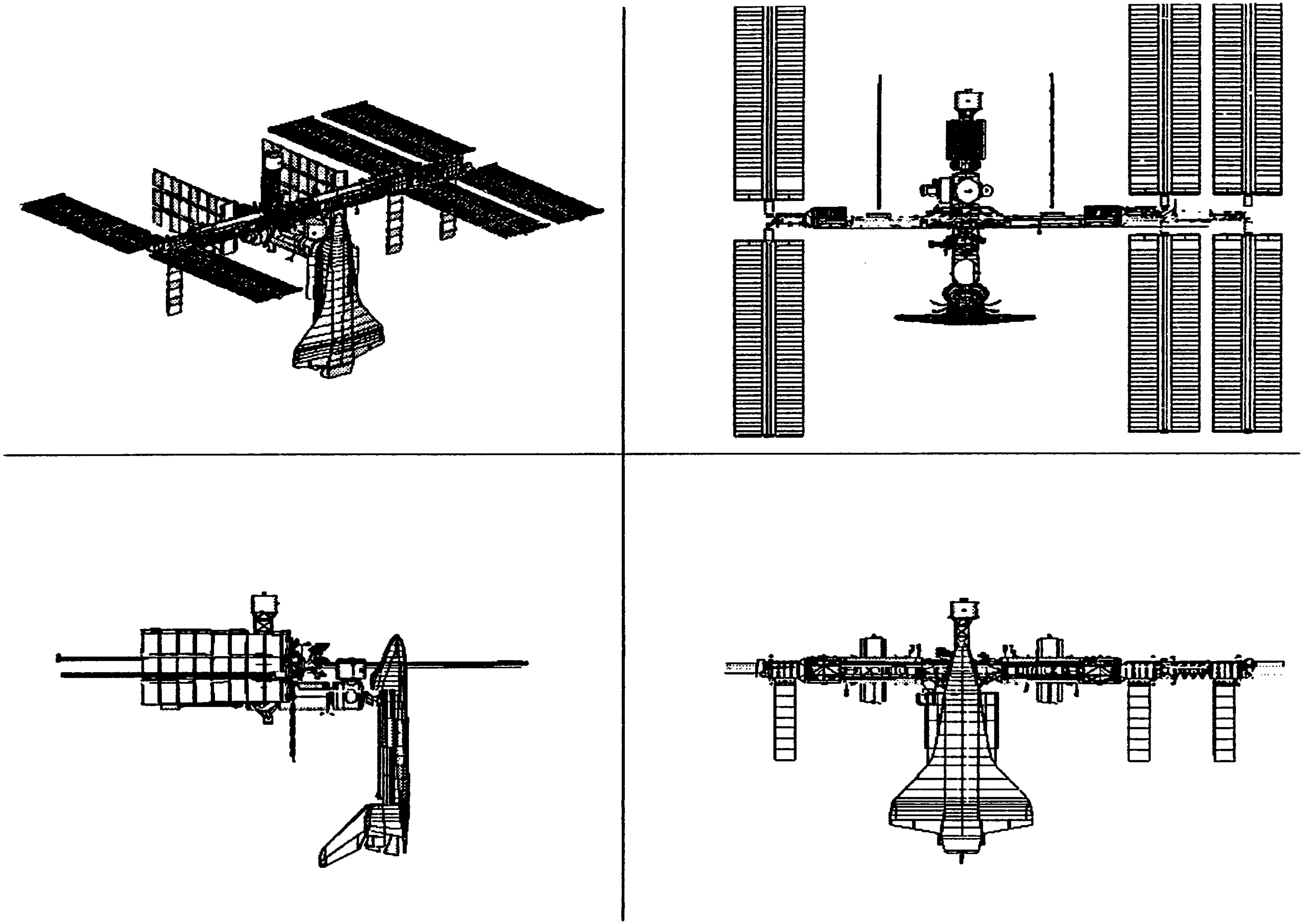


Figure 5.22.2-2 Stage 22 Configuration with Shuttle

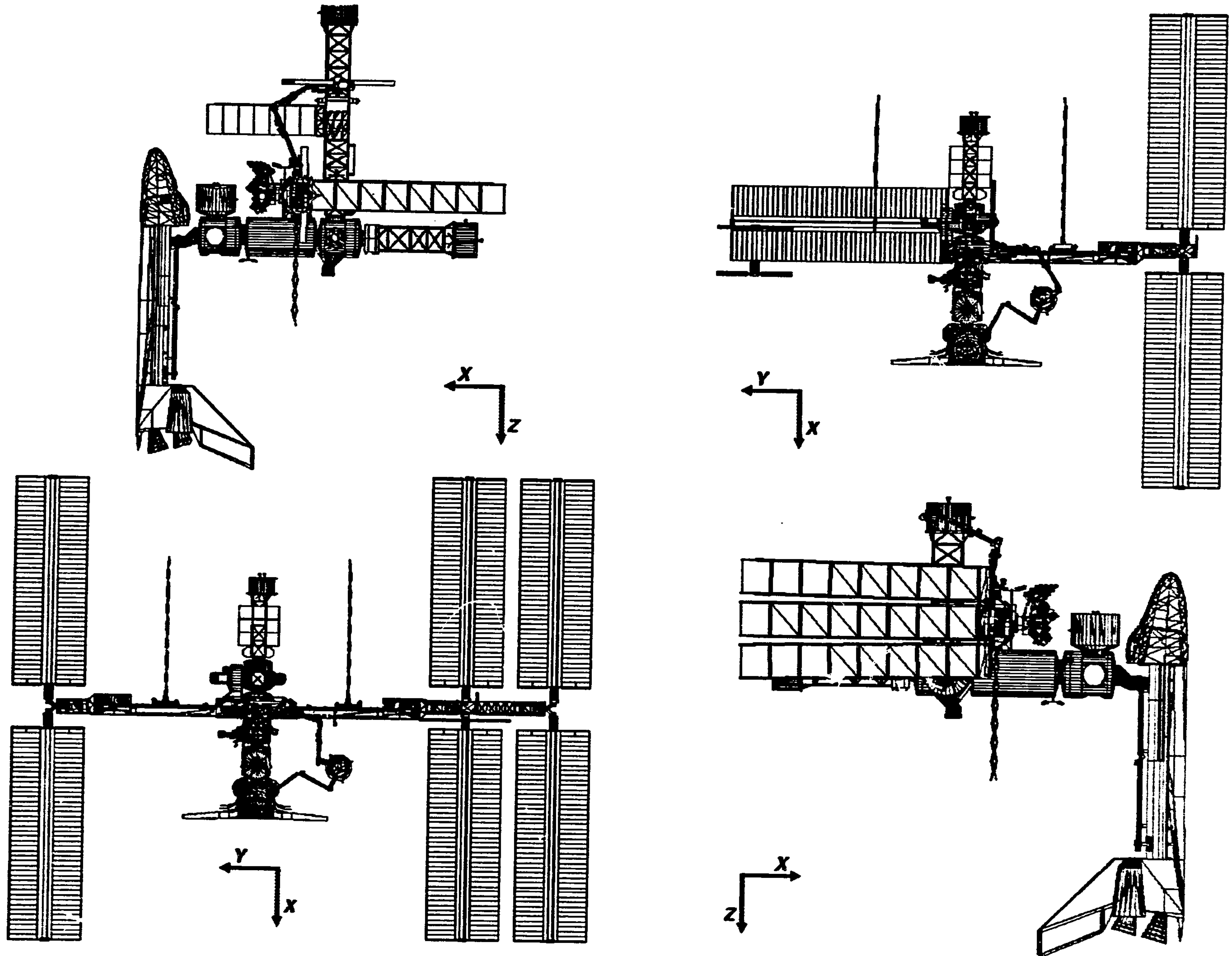


Figure 5.22.3–1 Zenith bus installation after removal of P6.

5.22.4 Stage 22, Flight 13A+ Performance Characteristics

Stage 22, Flight 13A+ is assembled at a 230 n.mi. altitude in an LVLH flight mode with 6 double axis articulating PV arrays. The nominal launch date is August, 2001.

Stage 22 in a $+2\sigma$ atmosphere (solar flux = 191.5, geomagnetic index = 22.1) has a flight attitude of yaw = 6.0, pitch = -3.3 , and roll = -0.9. The steady state microgravity environment is depicted in figure 5.22.4-1. Table 5.22.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given $+2\sigma$ atmosphere. This configuration contains 5 ISPR racks within the 1 μg environment.

Table 5.22.4-1 Stage 22 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.6
LAS-2	ISPR	1.6
LAS-3	ISPR	1.6
LAS-4	ISPR	1.6
LAS-5	SYS	1.5
LAS-6	SYS	1.5
LAF-1	SYS	2.1
LAF-2	SYS	2.1
LAF-3	SYS	2.1
LAF-4	SYS	2.1
LAF-5	SYS	2.0
LAF-6	SYS	2.0
LAP-1	ISPR	1.5
LAP-2	ISPR	1.5
LAP-3	ISPR	1.5
LAP-4	ISPR	1.4
LAP-5	SYS	1.4
LAP-6	SYS	1.4
LAC-1	ISPR	1.0
LAC-2	ISPR	1.0
LAC-3	ISPR	1.0
LAC-4	ISPR	1.0
LAC-5	ISPR	1.0
LAC-6	SYS	1.0

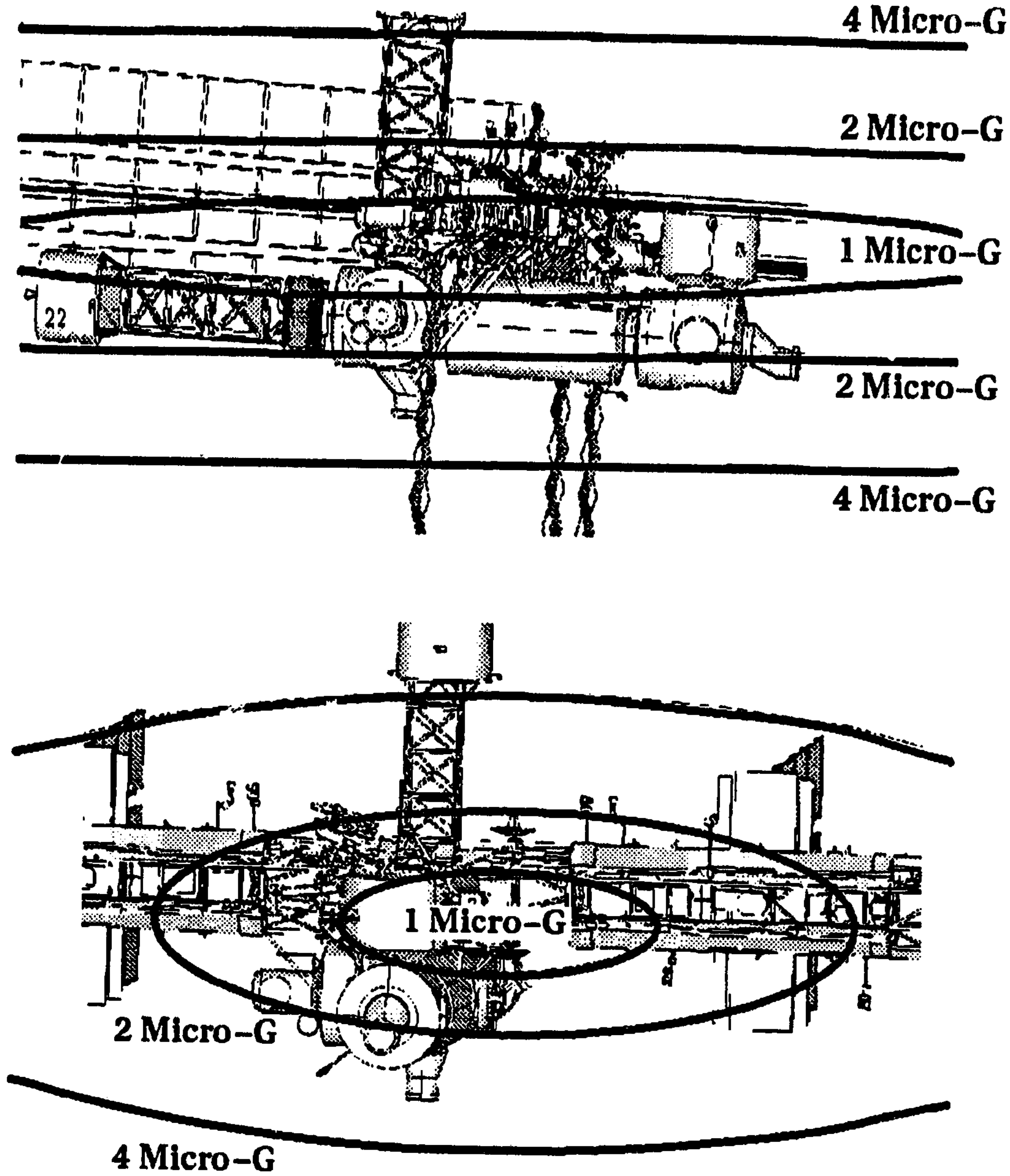


Figure 5.22.4-1 Stage 22 steady-state microgravity environment contours.

Table 5.22.4-2 summarizes the reboost lifetime characteristics of Stage 22 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 10.1 lbs/ft^2. The reboost is performed using the aft bus which currently has a reboost efficiency of 100%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.22.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	237	1,150	7,718	920	260

The control characteristics of Stage 22 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.22.4-2. Table 5.22.4-3 summarizes the control characteristics depicted in the plots.

Table 5.22.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	6.0 degrees	-4.5 degrees	-0.9 degrees	± 1.0 degrees	12,800 N-m-s
w/STS	32.4 degrees	43.8 degrees	-2.2 degrees	± 1.9 degrees	12,200 N-m-s

The control characteristics of Stage 22 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.22.4-3. Table 5.22.4-3 summarizes the control characteristics depicted in the plots.

5.22.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

In order to maintain progressive stage functionality, 6 EVAs were required to accommodate mission critical assembly tasks. In doing this, the initial EVA1 task time estimates exceeded the maximum planned EVA duration by more than 3 hours. In order to alleviate this condition the following changes are recommended:

> Remove the following EVA tasks from Flight 13A+ EVA1 and perform them on the next EVA: "Prep Upper EPS Equipment", "Prep Lower EPS Equipment", and "Rigidize 4 SARJ Braces". This will reduce the current 13A+ EVA1 to an acceptable 4 hours and 25 minutes.

Defer the current 13A+ EVA3 to Flight 2E, EVA1, which will now have a total EVA length of 5 hours 45 minutes.

The current EVA2 now becomes EVA3. It was felt that battery installation on S4 could be accomplished from the MT/SSRMS/SPDM operating from the ITS S3 MT rail and that the other deferred EVA tasks would not jeopardize stage functionality.

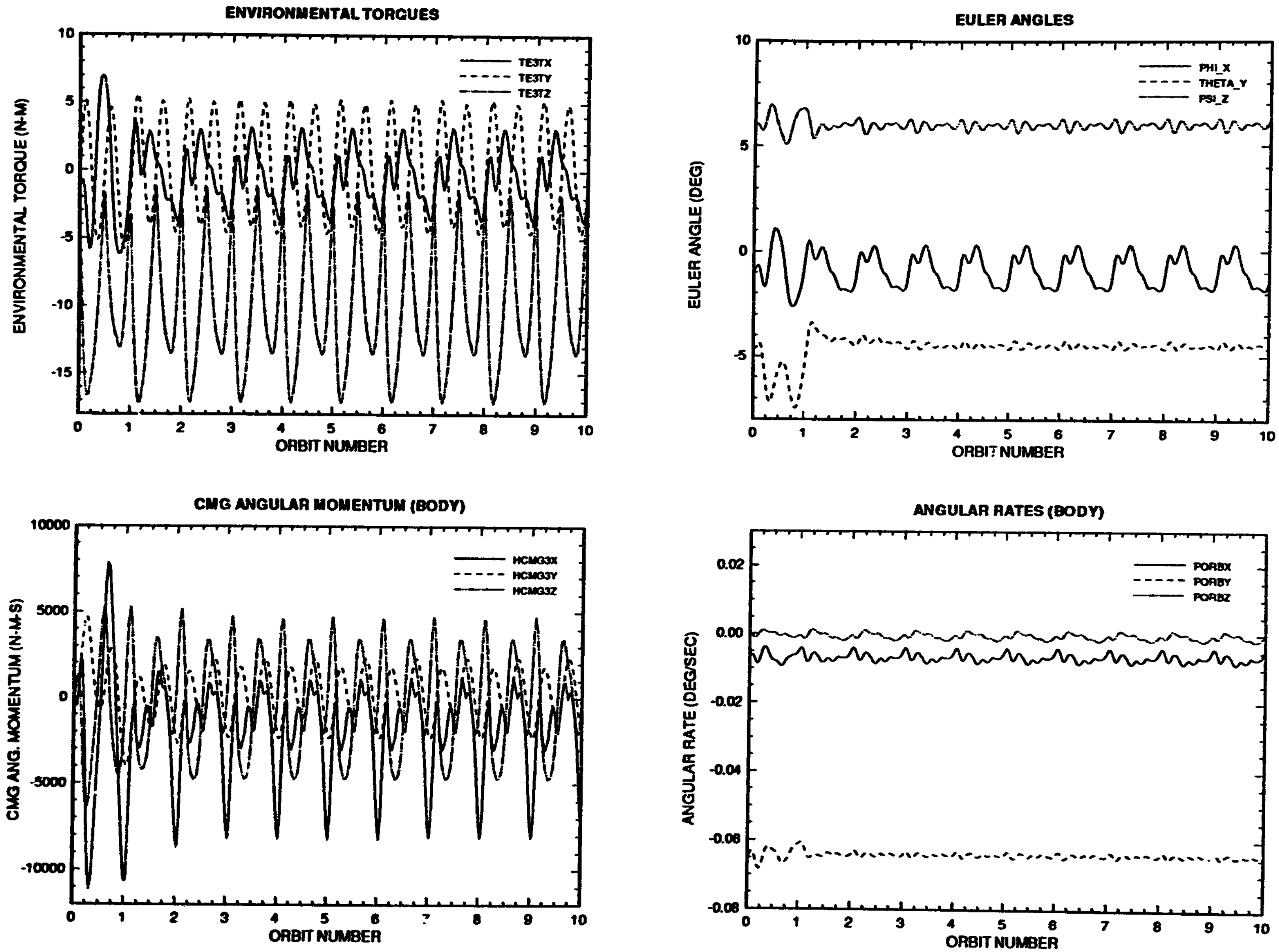


Figure 5.22.4-2 Stage 22 control plots without Shuttle attached.

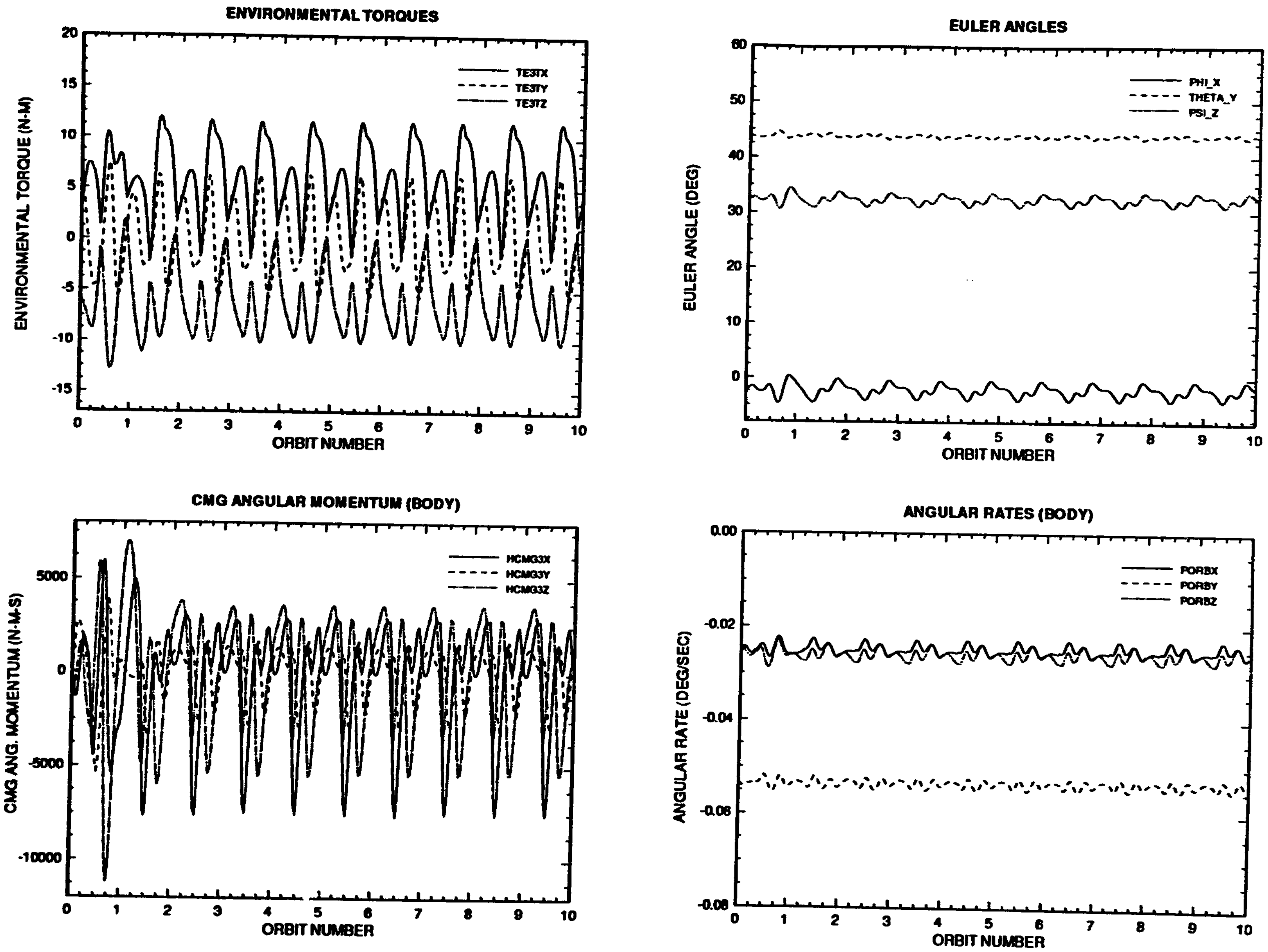


Figure 5.22.4-3 Stage 22 control plots with Shuttle attached.

5.23 Stage 23 Flight Characterization

5.23.1 Stage 23 - Flight UF-5 Shuttle Flight Manifest

Stage 23 is the fifth utilization flight. Table 5.23.1-1 lists the Shuttle Flight Manifest for Stage 23 - Flight UF-5. The total mass of the station hardware to orbit is ~9000 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 23176 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a mission flight margin of 536 lbs.

5.23.2 Stage 23 Configuration

Figure 5.23.2-1 displays the isometric view of Stage 23 after the Shuttle departs and the scheduled assembly is completed. Figure 5.23.2-2 shows the front, side, top and isometric views of Stage 23 with the Shuttle attached.

5.23.3 Flight UF-5 Assembly Operations Description

Rendezvous of the Shuttle with the Stage 22 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight UF-5 is a 12 day mission with 0 EVAs. The SRMS unberths the MPLM from the Shuttle payload bay and installs it on the Node 2 nadir port CBM. Upon completion of the rack exchange, the MPLM is returned to payload bay.

Following separation, Stage 23 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

<u>System Resource/Functionality</u>

Stage 22 functionality, plus:

- No additional functionality added on this flight

Resources Available:	*Power:*	*47,200 W*	
	Thermal:	*TBD*	
	EVA:	*0 crew-hours*	
Resources Required:	*Power:*	*13,392 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		229 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*0 crew-hours*	

Table 5.23.1-1 Stage 23 - Flight UF-5 Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
MPLM		10705
ISPRs	TBD	
ULC		2935
Attached Payload	TBD	
subtotal	**9000**	**13640**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-2314
APCU-I	714	
ROFU	450	
Additional Attach Hardware	990	
Misc. hardware	160	
	2314	
Variable Shuttle Consumables		-3161
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	330	
5th & 6th N2 tanks (@128 lbs/N2)	256	
5th Cryo Tank & Fluid	1575	
	3161	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1500
Maintenance Reserve		-1000
Total Shuttle Lift Capability		**23176**
Mission Flight Margin		**536**

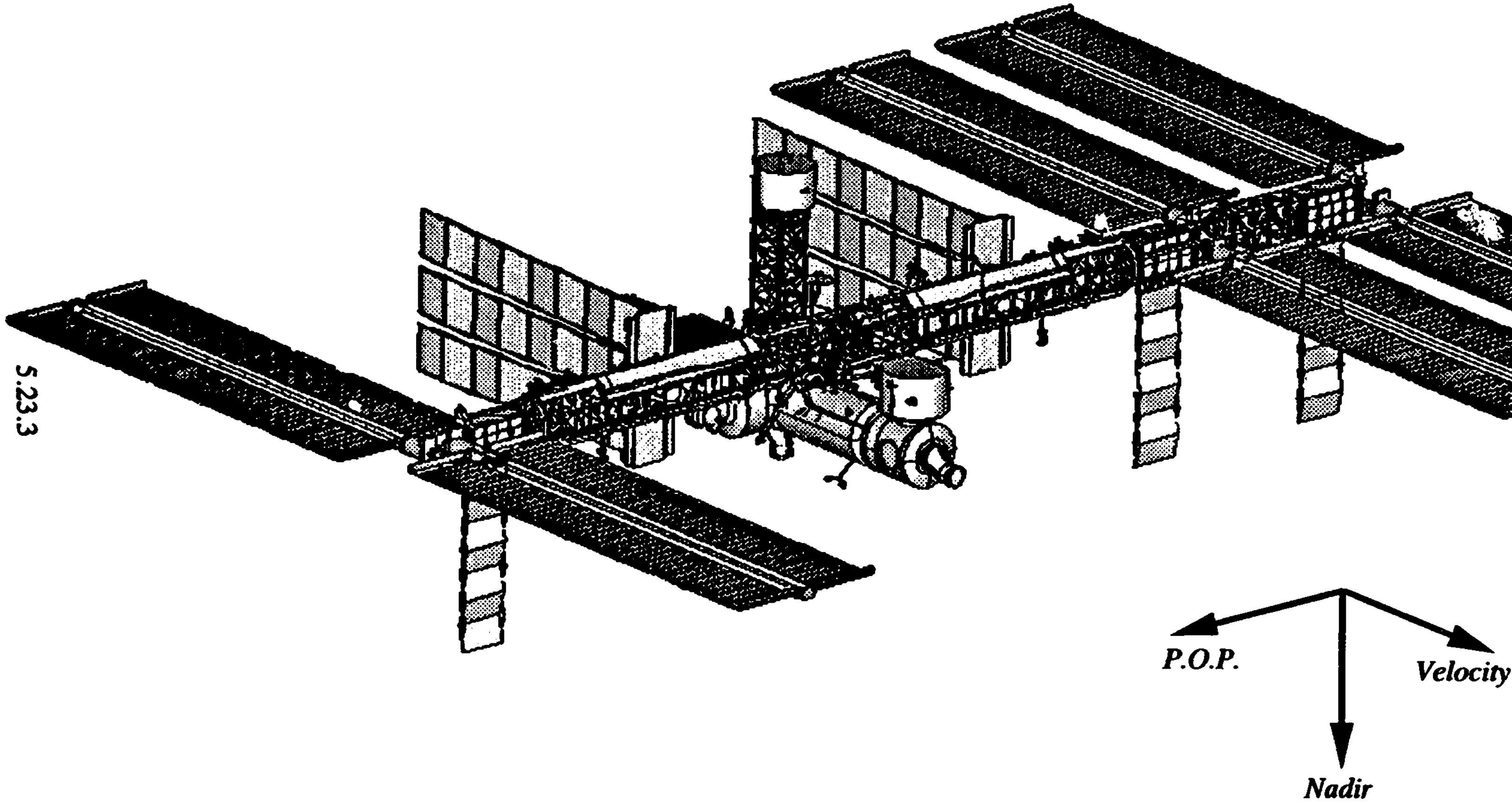


Figure 5.23.2–1 Stage 23 Configuration

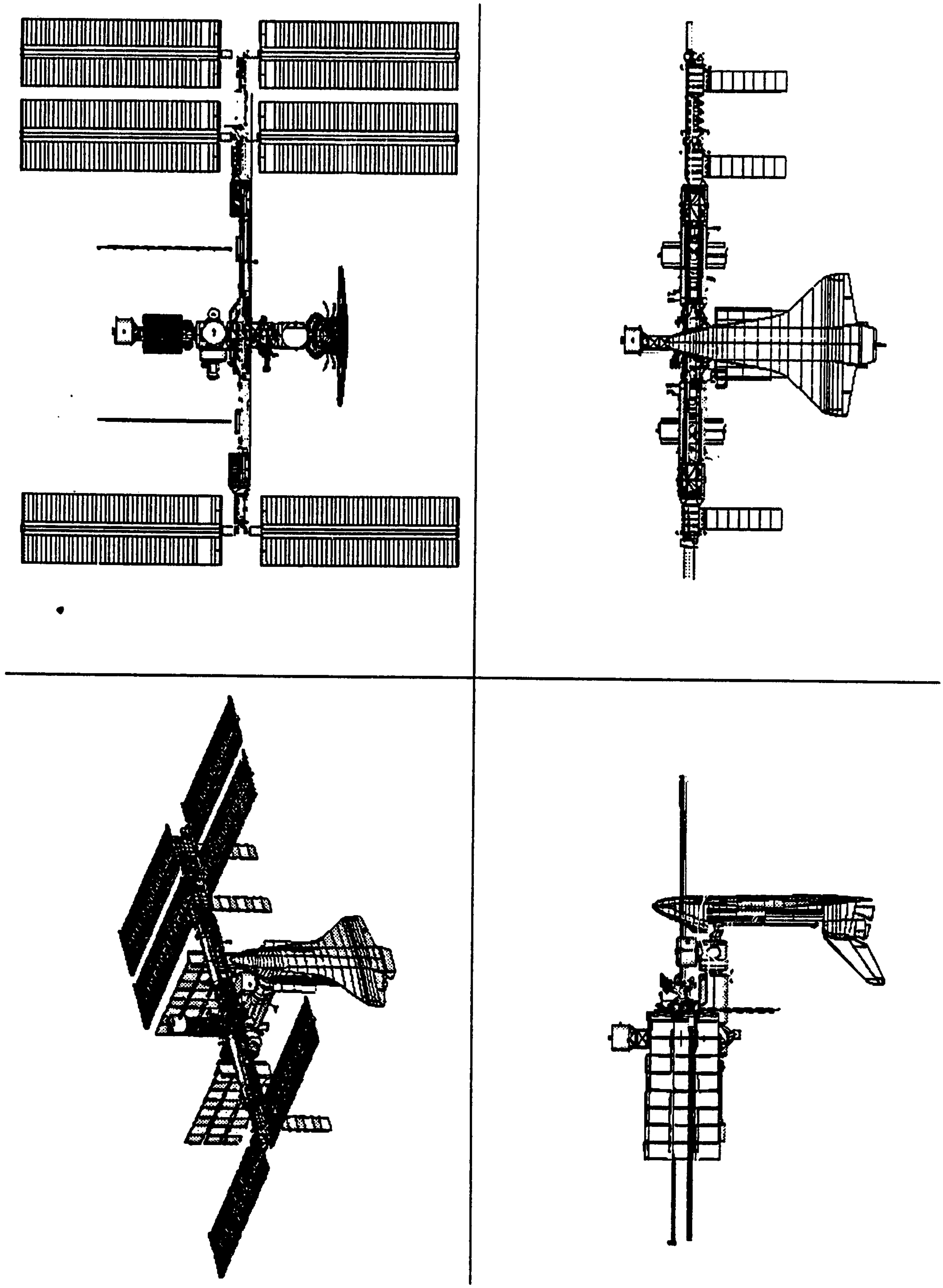


Figure 5.23.2-2 Stage 23 Configuration with Shuttle

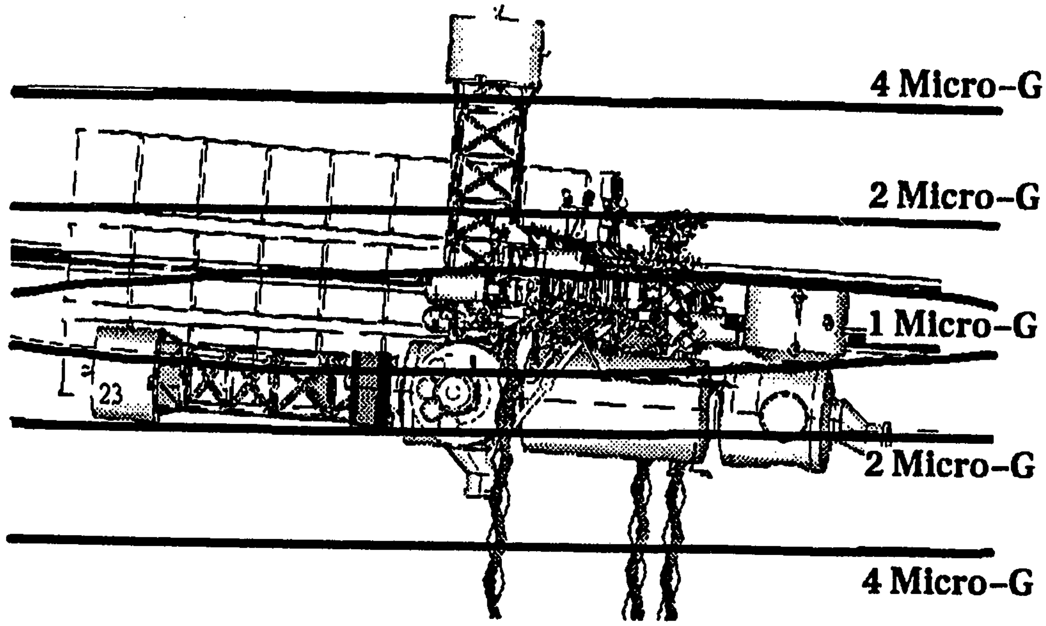
5.23 Stage 23, Flight UF-5 Performance Characteristics

Stage 23, Flight UF-5 is assembled at a 230 n.mi. altitude in an LVLH flight mode with 3 double axis articulating PV arrays. The nominal launch date is October, 2001.

Stage 23 in a +2σ atmosphere (solar flux = 182.9, geomagnetic index = 22.5) has a flight attitude of yaw = 6.0, pitch = -3.1 , and roll = -0.9. The steady state microgravity environment is depicted in figure 5.23.4-1. Table 5.23.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 5 ISPR racks within the 1 μg environment.

Table 5.23.4-1 Stage 23 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.6
LAS-2	ISPR	1.6
LAS-3	ISPR	1.6
LAS-4	ISPR	1.5
LAS-5	SYS	1.5
LAS-6	SYS	1.5
LAF-1	SYS	2.1
LAF-2	SYS	2.1
LAF-3	SYS	2.1
LAF-4	SYS	2.0
LAF-5	SYS	2.0
LAF-6	SYS	2.0
LAP-1	ISPR	1.5
LAP-2	ISPR	1.5
LAP-3	ISPR	1.4
LAP-4	ISPR	1.4
LAP-5	SYS	1.4
LAP-6	SYS	1.4
LAC-1	ISPR	1.0
LAC-2	ISPR	1.0
LAC-3	ISPR	1.0
LAC-4	ISPR	1.0
LAC-5	ISPR	1.0
LAC-6	SYS	1.0



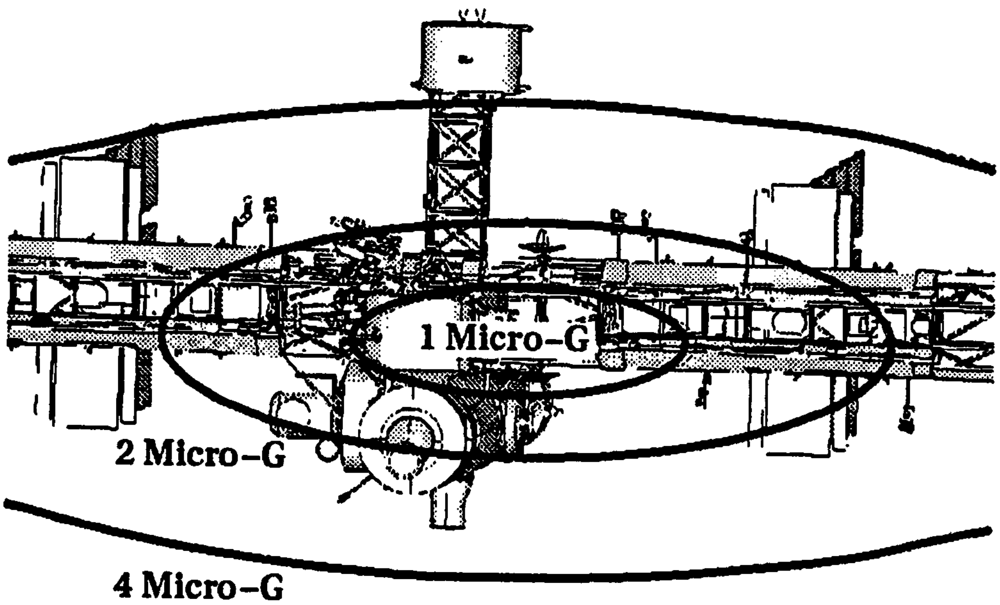


Figure 5.23.4-1 Stage 23 steady-state microgravity environment contours.

Table 5.23.4-2 summarizes the reboost lifetime characteristics of Stage 23 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 10.1 lbs/ft^2. The reboost is performed using the zenith bus which currently has a reboost efficiency of 92%. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.23.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	237	1,285	7,718	-365	290

The controls results are identical to those described in 5.22.4 in the design atmosphere.

5.23.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

5.24 Stage 24 Flight Characterization

5.24.1 Stage 24 - Flight 1J Shuttle Flight Manifest

The Shuttle delivers the JEM PM. Table 5.24.1-1 lists the Shuttle Flight Manifest for Stage 24 - Flight 1J. The total mass of the station hardware to orbit is 30864 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 29058 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a negative mission flight margin of -1806 lbs. This flight was delivered to a higher altitude than the Baseline 9/28/94 Assembly Sequence, therefore the mission flight margin is even more negative.

5.24.2 Stage 24 Configuration

Figure 5.24.2-1 displays the isometric view of Stage 24 after the Shuttle departs and the scheduled assembly is completed. Figure 5.24.2-2 shows the front, side, top and isometric views of Stage 24 with the Shuttle attached.

5.24.3 Flight 1J Assembly Operations Description

Rendezvous of the Shuttle with the Stage 23 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 1J is a 9 day mission with 2 EVAs. The SRMS unberths the JEM PM from the Shuttle payload bay and attaches the element to the Node 2 port CBM. The SSRMS unberths the JEM ELM PS from the Node 2 zenith port and attaches the unit to the JEM PM zenith port. The JEM RMS is installed, checked-out and activated.

Following separation, Stage 24 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 23 functionality, plus:

- JEM attached to Node 2, port-side port
- Delivers and activates the JEM Pressurized Module and the JEM RMS
- Relocate ELM-PS to JEM PM
- JEM PM PDGF checked out

Resources Available:	*Power:*	*47,200 W*	
	Thermal:	*TBD*	
	EVA:	*24 crew-hours*	
Resources Required:	*Power:*	*13,392 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		4,902 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*14:30 crew-hours*	

Table 5.24.1-1 Stage 24 - Flight 1J Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
JEM PM (with 3 system racks)		
JEM Pressurized Module Core	25696	
JEM PM DMS 2 Rack	939	
JEM PM THC/TCS 2 Rack	1166	
JEM PM EPS 2 Rack	866	
JEM Robotic Manipulator System	2196	
subtotal	**30864**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		0
Variable Shuttle Consumables		-293
Food & Gear (-55 lbs/day over 6)	165	
5th N2 tank (@128 lbs/tank)	128	
	293	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1340
Maintenance Reserve		-460
Total Shuttle Lift Capability		**29058**

Mission Flight Margin		**-1806**

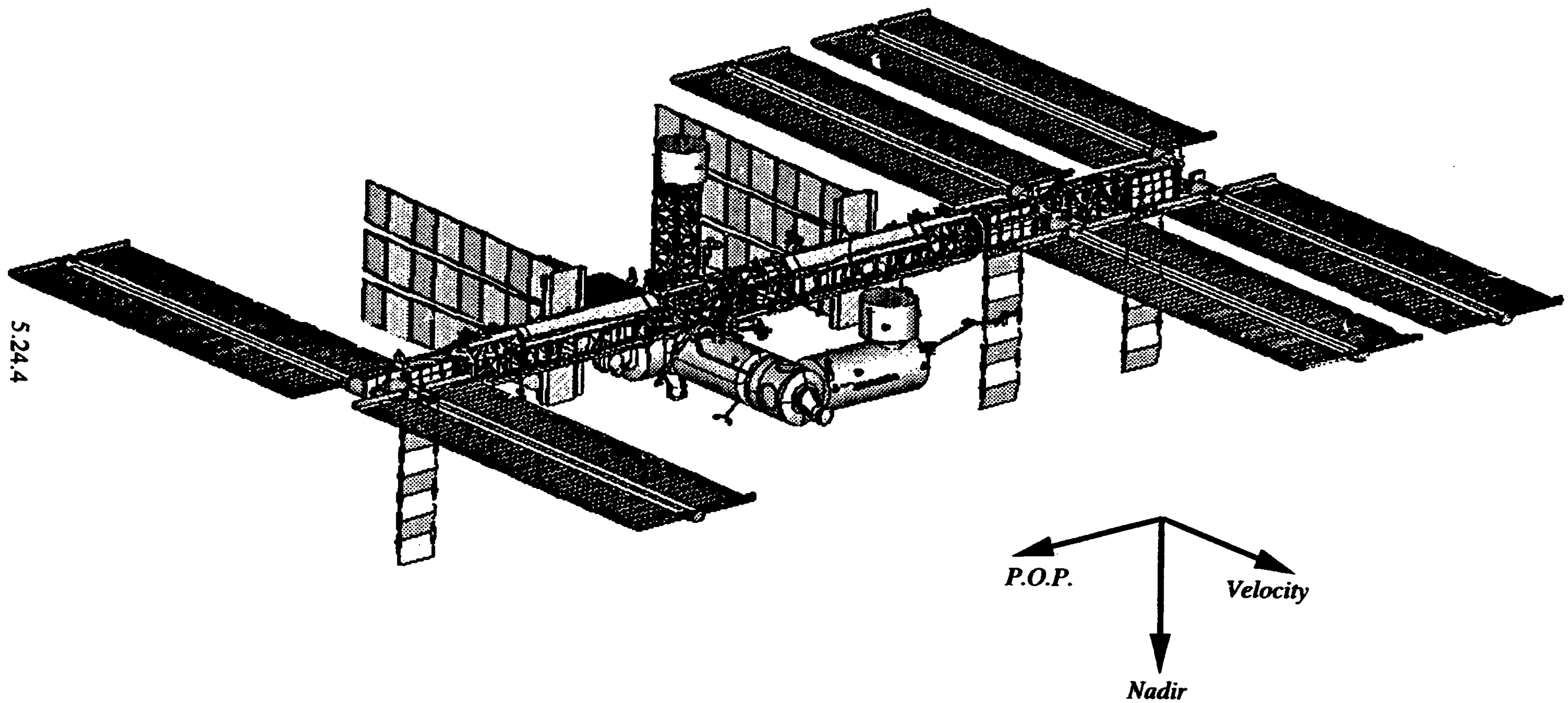


Figure 5.24.2–1 Stage 24 Configuration

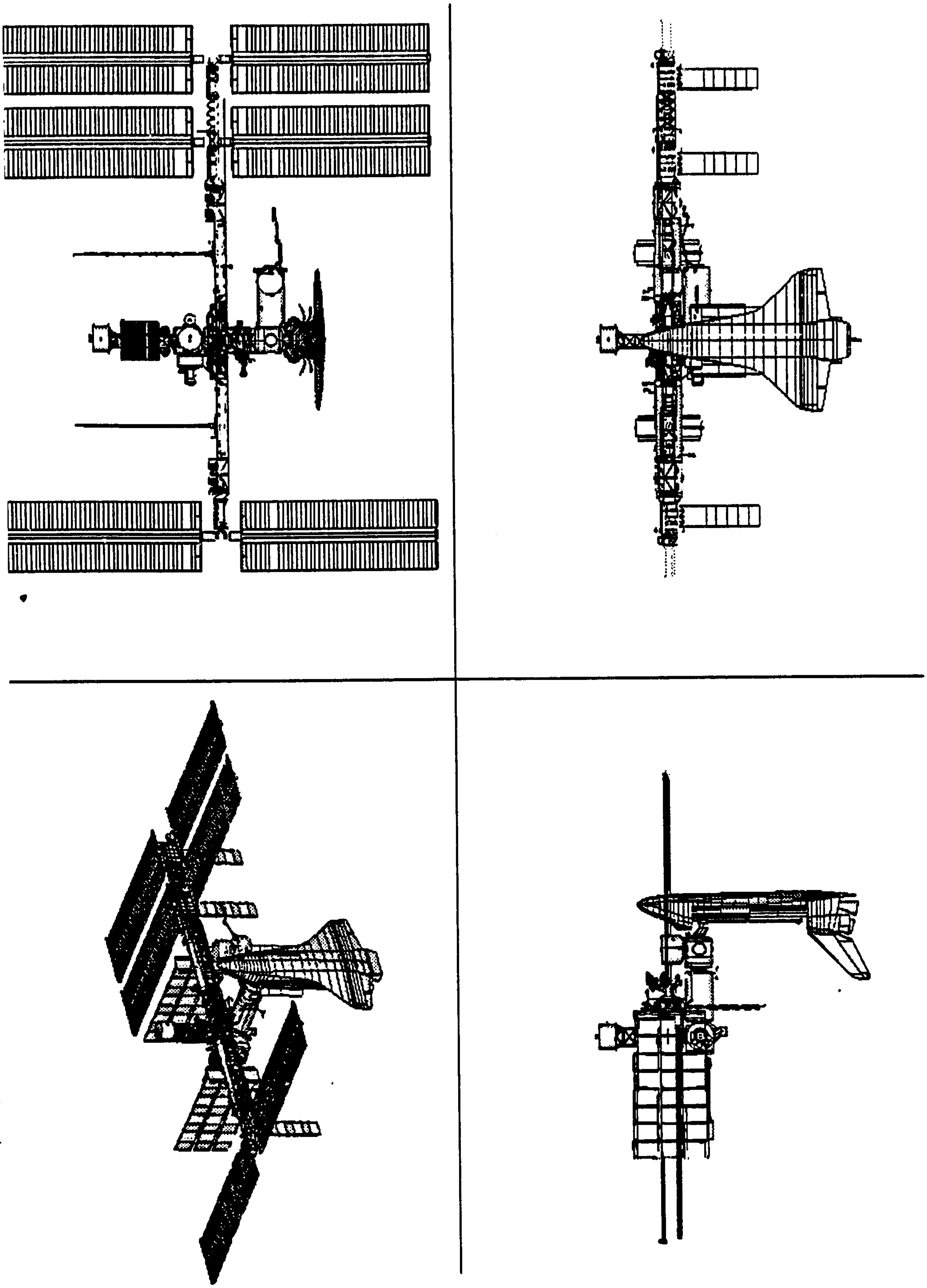


Figure 5.24.2-2 Stage 24 Configuration with Shuttle

5.24.4 Stage 24, Flight 1J Performance Characteristics

Stage 24, Flight 1J is assembled at a 230 n.mi. altitude in an LVLH flight mode with 3 pair of double axis articulating PV arrays. The nominal launch date is December, 2001.

Stage 24 in a +2σ atmosphere (solar flux = 176.3, geomagnetic index = 22.5) has a flight attitude of yaw = 1.5, pitch = 2.6 , and roll = -0.9. The steady state microgravity environment is depicted in figure 5.24.4-1. Table 5.24.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 5 ISPR racks within the 1 μg environment.

Table 5.24.4-1 Stage 24 US Lab Racks Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.3
LAS-2	ISPR	1.4
LAS-3	ISPR	1.4
LAS-4	ISPR	1.4
LAS-5	SYS	1.4
LAS-6	SYS	1.4
LAF-1	SYS	1.8
LAF-2	SYS	1.8
LAF-3	SYS	1.8
LAF-4	SYS	1.9
LAF-5	SYS	1.9
LAF-6	SYS	1.9
LAP-1	ISPR	1.2
LAP-2	ISPR	1.2
LAP-3	ISPR	1.2
LAP-4	ISPR	1.2
LAP-5	SYS	1.3
LAP-6	SYS	1.3
LAC-1	ISPR	0.8
LAC-2	ISPR	0.8
LAC-3	ISPR	0.8
LAC-4	ISPR	0.8
LAC-5	ISPR	0.9
LAC-6	SYS	0.9

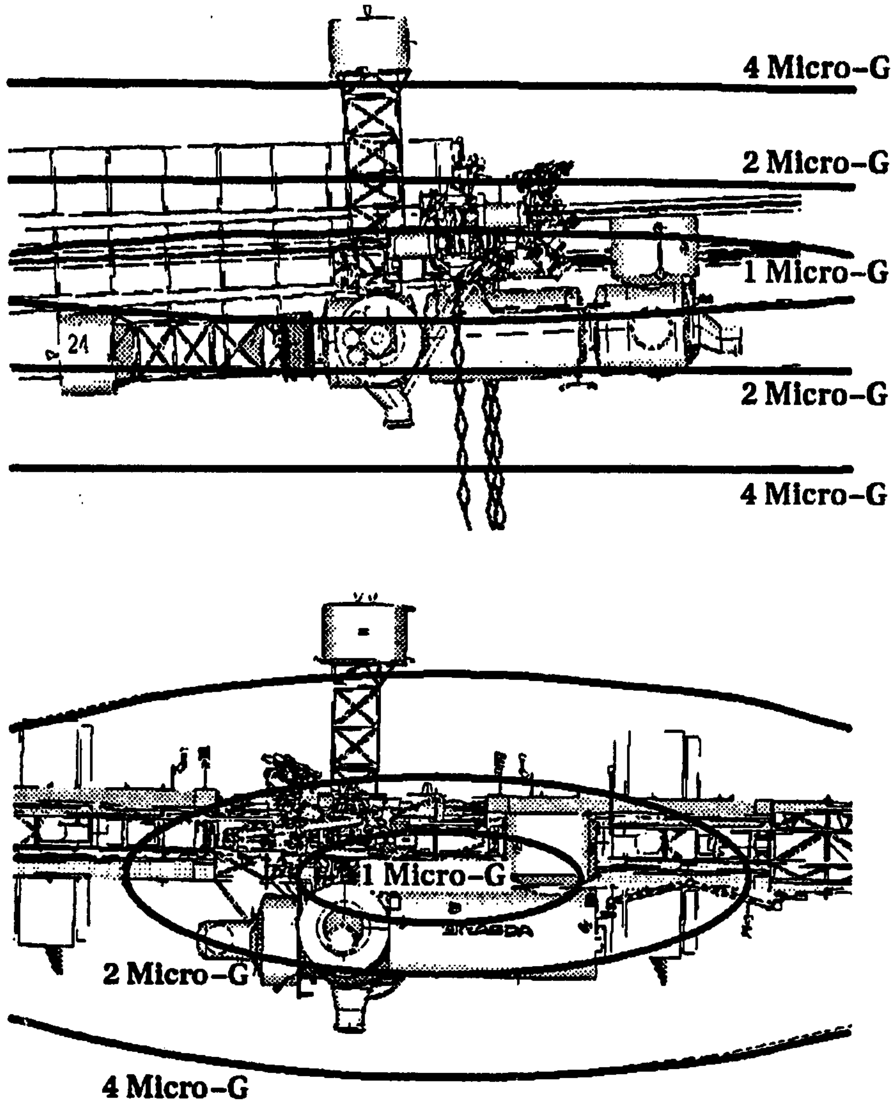


Figure 5.24.4-1 Stage 24 steady-state microgravity environment contours.

Table 5.24.4-2 summarizes the reboost lifetime characteristics of Stage 24 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 10.7 lbs/ft^2. The reboost is performed using the aft bus which currently has a reboost efficiency of 100%, while the zenith bus has fully expended its propellant load. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.24.4-2 Reboost lifetime characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	240	1,859	5,859	-365	169

The control characteristics of Stage 24 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.24.4-2. Table 5.24.4-3 summarizes the control characteristics depicted in the plots.

Table 5.24.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	4.3 degrees	1.0 degrees	-0.9 degrees	± 1.0 degrees	12,500 N-m-s
w/STS	33.6 degrees	43.6 degrees	-3.5 degrees	± 2.1 degrees	11,000 N-m-s

The control characteristics of Stage 24 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.24.5-3. No momentum wheel augmentation was required. Table 5.24.4-3 summarizes the control characteristics depicted in the plots. The presence of the Shuttle results in large pitch and yaw torque equilibrium angles.

5.24.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

There is a negative weight margin for the Shuttle manifest which will require weight reduction or utilization of reserve performance margins.

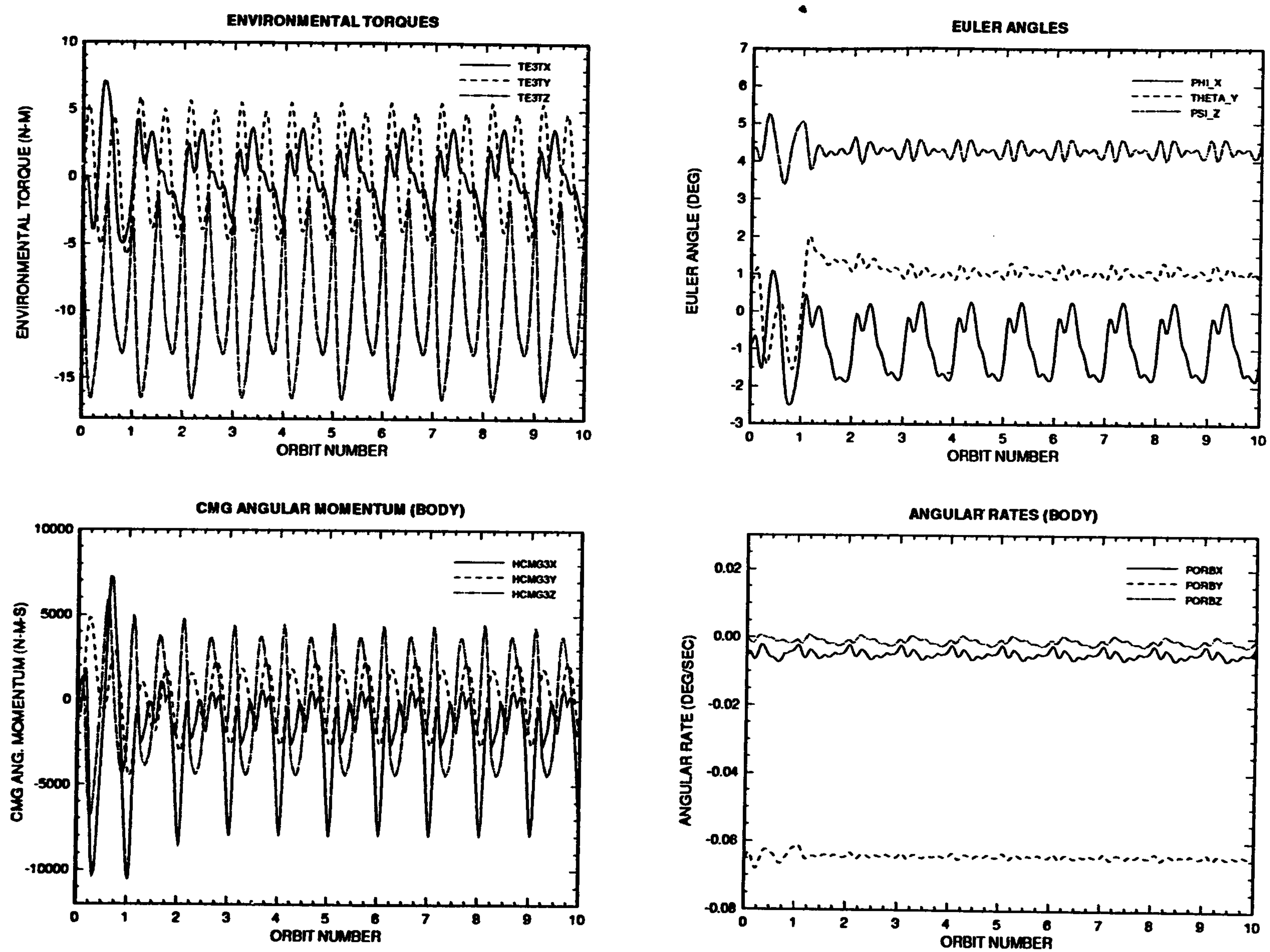


Figure 5.24.4-2 Stage 24 control plots without Shuttle attached.

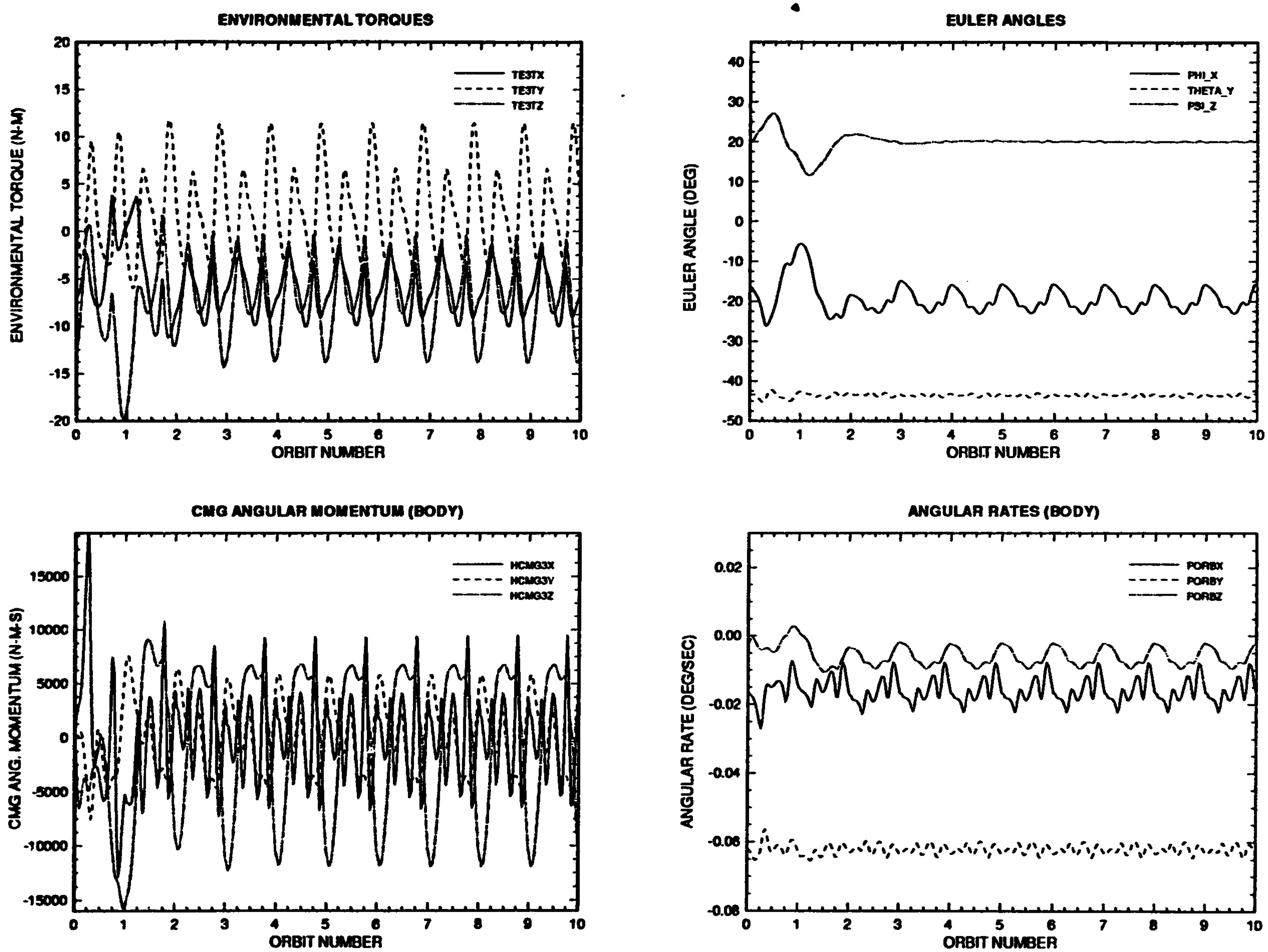


Figure 5.24.4-3 Stage 24 control plots with Shuttle attached.

5.25 Stage 25 Flight Charaterization

5.25.1 Stage 25 - Flight 2E Shuttle Flight Manifest

This flight carries the outfitting for the European Space Agency Pressurized Module as well as JEM system and stowage racks in the MPLM and delivers the S5 truss segment. Table 5.25.1-1 lists the Shuttle Flight Manifest for Stage 25 - Flight 2E. The total mass of the station hardware to orbit is 13229 lbs. The second section of the table shows the Orbiter Performance and hardware/consumables required for the mission resulting in the net Orbiter Lift Capability of 27138 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 3283 lbs.

5.25.2 Stage 25 Configuration

Figure 5.25.2-1 displays the isometric view of Stage 25 after the orbiter departs and the scheduled assembly is completed. Figure 5.25.2-2 shows the front, side, top and isometric views of Stage 25 with the orbiter attached.

5.25.3 Flight 2E Assembly Operations Description

Rendezvous of the Shuttle with the Stage 24 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 2E is a 9 day mission with 1 EVA. The SRMS removes the MPLM from the payload bay and berths it to Node 2 nadir CBM. Upon completion of U.S./APM stowage rack transfers, the MPLM is returned to the payload bay. The SSRMS directly unberths the S5 truss segment from the payload bay and attaches the element to the MBS Payload/ORU Accommodation (POA). The SSRMS installs the S5 ITS to the outboard side of the S4 ITS, and the utilities are connected during the single EVA for this flight.

Following separation, Stage 25 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

<u>System Resource/Functionality</u>

Stage 24 functionality, plus:

- Delivers and activates remaining JEM Racks

Resources Available:	*Power:*	*47,200 W*	
	Thermal:	*TBD*	
	EVA:	*12 crew-hours*	
Resources Required:	*Power:*	*13,392 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		4,902 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*6:30 crew-hours*	

Table 5.25.1-1 Stage 25 - Flight 2E Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
MPLM		10626
Node 1 Stowage Rack 1	783	
Node 1 Stowage Rack 2	779	
JEM PM System Stowage Rack 2	873	
JEM PM outfitting, workbench	613	
JEM small fine arm	351	
JEM ELM-PS/US Stowage Rack 1	998	
JEM ELM-PS Stowage Rack 1	642	
JEM ELM-PS Stowage Rack 2	920	
JEM ELM-PS Stowage Rack 3	916	
JEM ELM-PS Stowage Rack 4	972	
JEM ELM-PS Stowage Rack 5	972	
APM/US Stowage Rack 2	882	
S5 truss segment	3528	
subtotal	**13229**	**10626**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-790
Additional Attach Hardware	790	
	790	
Variable Shuttle Consumables		-293
Food & Gear (-55 lbs/day over 6)	165	
5th N2 tanks (@128 lbs/N2)	128	
	293	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-2130
Maintenance Reserve		-800
Total Shuttle Lift Capability		**27138**
Mission Flight Margin		**3283**

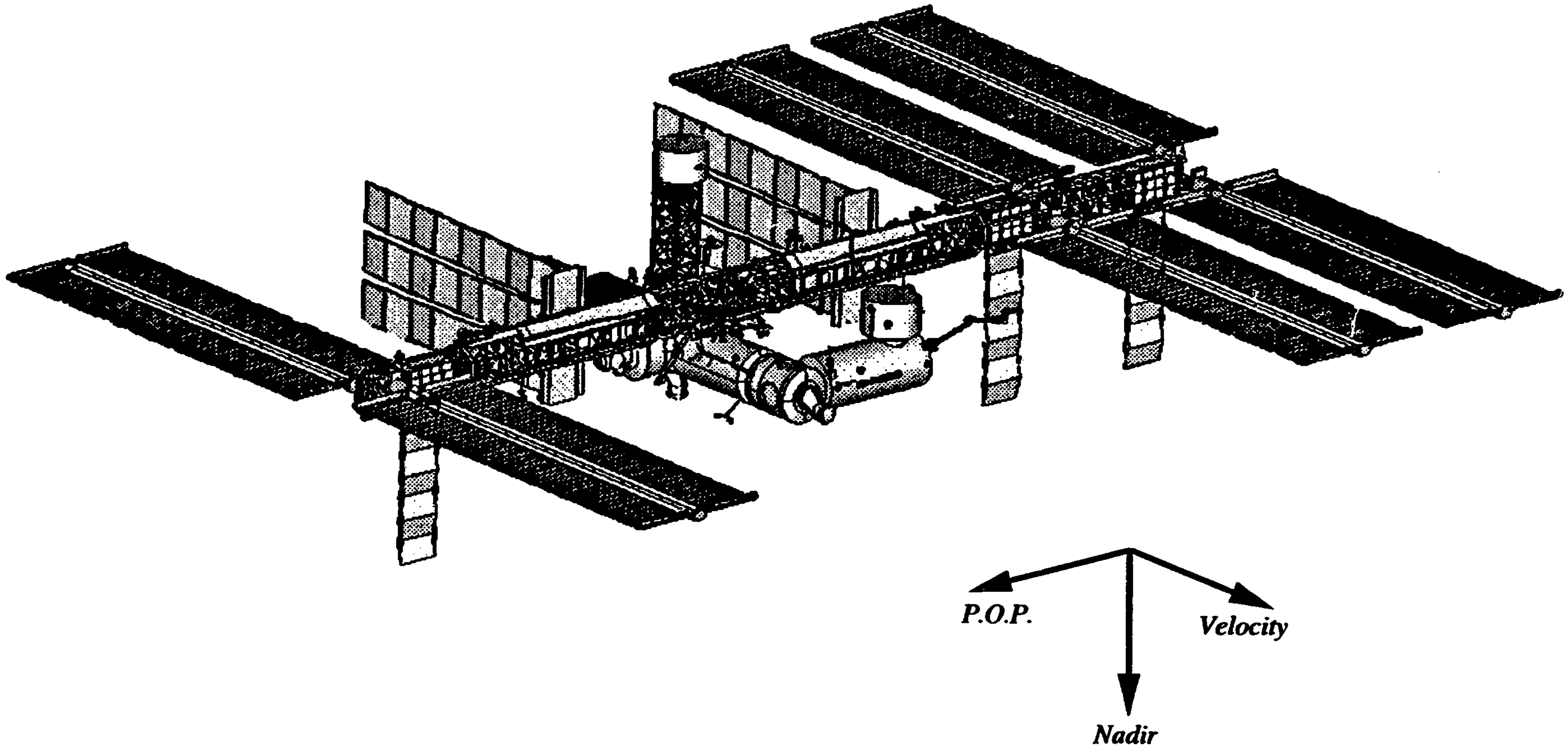


Figure 5.25.2-1 Stage 25 Configuration

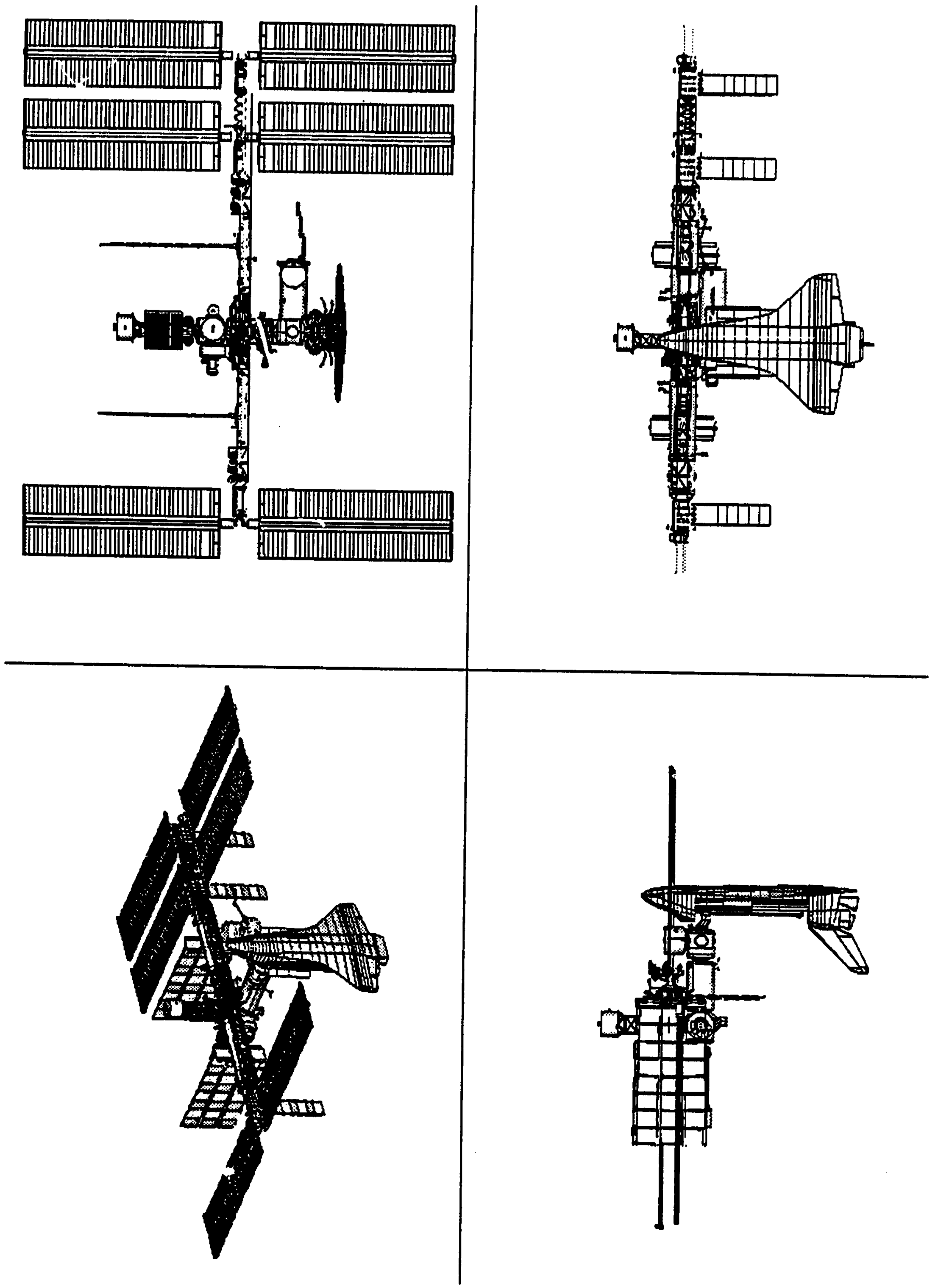


Figure 5.25.2-2 Stage 25 Configuration with Shuttle

5.25 Stage 25, Flight 2E Performance Characteristics

Stage 25, Flight 2E is assembled at a 230 n.mi. altitude in an LVLH flight mode with 3 pair of double axis articulating PV arrays. The nominal launch date is February, 2002.

Stage 25 in a +2σ atmosphere (solar flux = 171.1, geomagnetic index = 21.0) has a flight attitude of yaw = 0.0, pitch = 2.6 , and roll = -0.7. The steady state microgravity environment is depicted in figure 5.25.4-1. Table 5.25.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 5 ISPR racks within the 1 μg environment.

Table 5.25.4-1 Stage 25 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.3
LAS-2	ISPR	1.3
LAS-3	ISPR	1.4
LAS-4	ISPR	1.4
LAS-5	SYS	1.4
LAS-6	SYS	1.4
LAF-1	SYS	1.8
LAF-2	SYS	1.8
LAF-3	SYS	1.8
LAF-4	SYS	1.9
LAF-5	SYS	1.9
LAF-6	SYS	1.9
LAP-1	ISPR	1.2
LAP-2	ISPR	1.2
LAP-3	ISPR	1.2
LAP-4	ISPR	1.2
LAP-5	SYS	1.3
LAP-6	SYS	1.3
LAC-1	ISPR	0.7
LAC-2	ISPR	0.8
LAC-3	ISPR	0.8
LAC-4	ISPR	0.8
LAC-5	ISPR	0.8
LAC-6	SYS	0.9

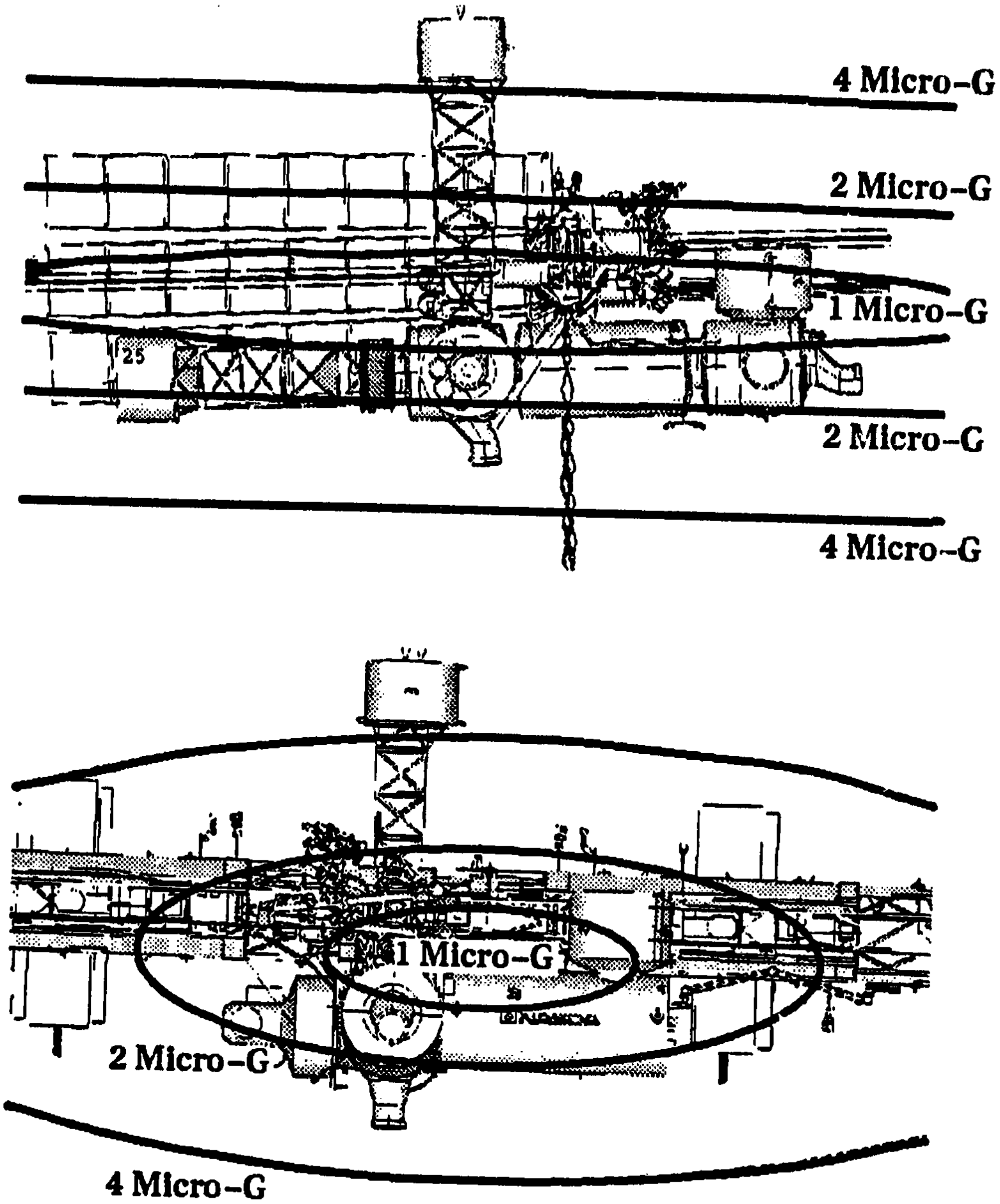


Figure 5.25.4-1 Stage 25 steady-state microgravity environment contours.

Table 5.25.4-2 summarizes the reboost lifetime characteristics of Stage 25 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 10.8 lbs/ft^2. The reboost is performed using the aft bus which currently has a reboost efficiency of 100%, while the zenith bus has fully expended its propellant load. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.25.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	240	1,792	4,068	-365	197

The control characteristics of Stage 25 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.25.4-2. Table 5.25.4-3 summarizes the control characteristics depicted in the plots.

Table 5.25.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	3.6 degrees	0.9 degrees	-0.7 degrees	± 1.0 degrees	13,900 N-m-s
w/STS	31.0 degrees	43.6 degrees	-3.3 degrees	± 2.0 degrees	13,700 N-m-s

The control characteristics of Stage 25 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.25.4-3. Table 5.25.4-3 summarizes the control characteristics depicted in the plots.

5.25.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

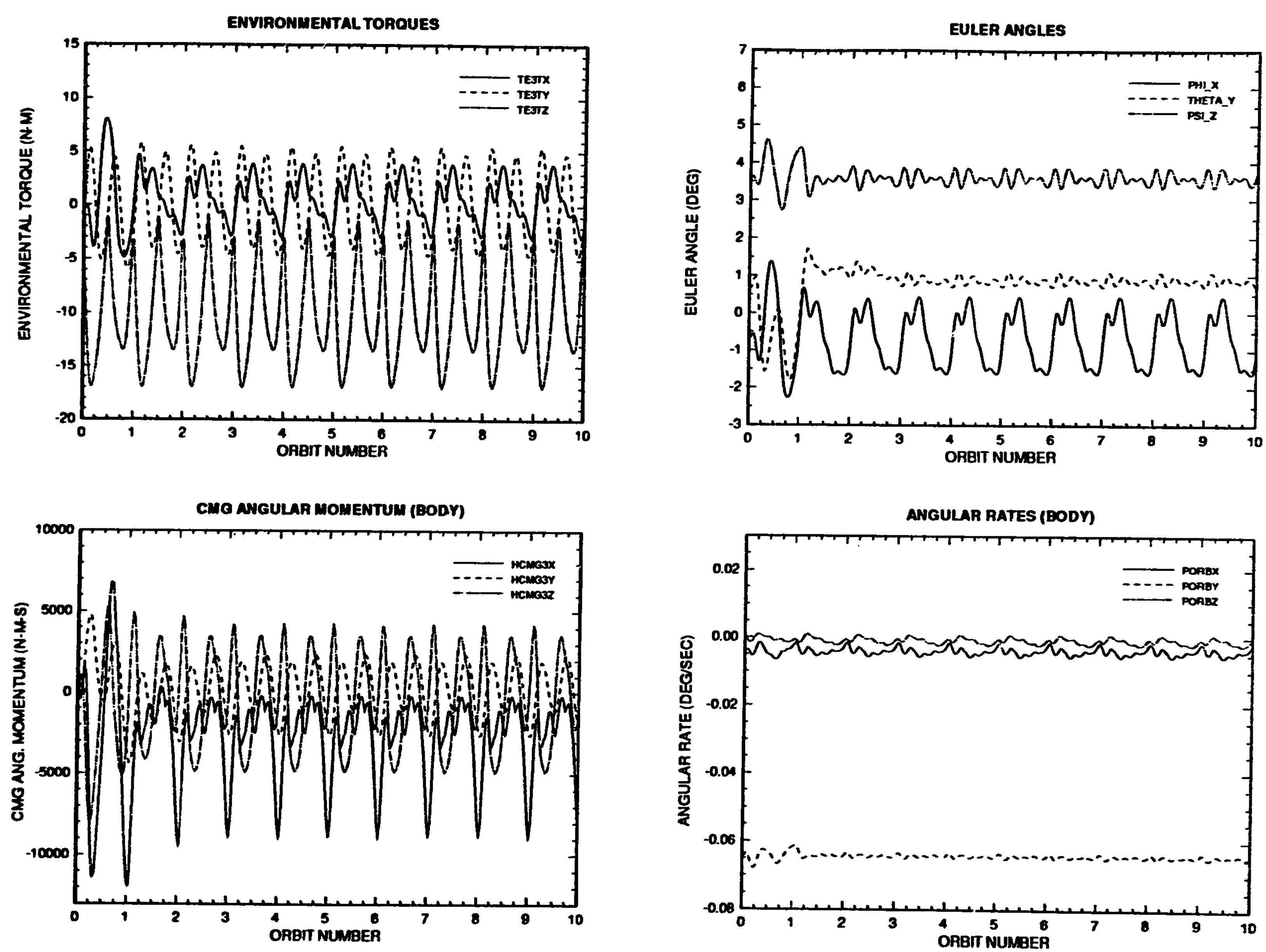


Figure 5.25.4-2 Stage 25 control plots without Shuttle attached.

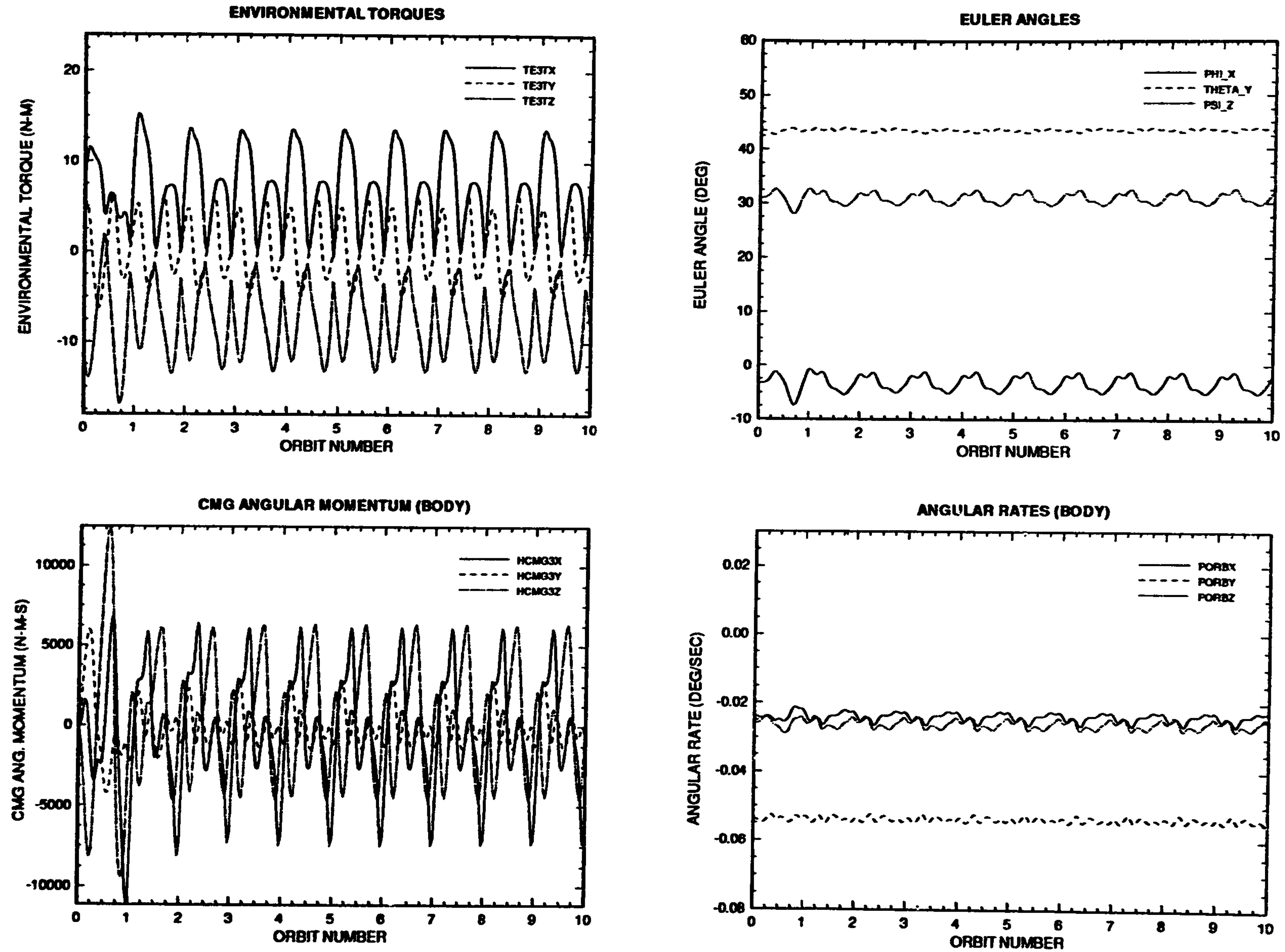


Figure 5.25.4-3 Stage 25 control plots with Shuttle attached.

5.26 Stage 26 Flight Charaterization

5.26.1 Stage 26 - Flight UF-6 Shuttle Flight Manifest

The sixth utilization flight is dedicated to outfitting the Japanese Experiment Module (JEM). Table 5.26.1-1 lists the Shuttle Flight Manifest for Stage 26 - Flight UF-6. The total mass of the station hardware to orbit is ~13000 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 24664 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 959 lbs.

5.26.2 Stage 26 Configuration

Figure 5.26.2-1 displays the isometric view of Stage 26 after the Shuttle departs and the scheduled assembly is completed. Figure 5.26.2-2 shows the front, side, top and isometric views of Stage 26 with the Shuttle attached.

5.26.3 Flight UF-6 Assembly Operations Description

Rendezvous of the Shuttle with the Stage 25 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight UF-6 is a 12 day mission with 0 EVAs. The SRMS unberths the MPLM from the Shuttle payload bay and installs it on the Node 2 nadir port CBM. Upon completion of the rack exchange, the MPLM is returned to payload bay.

Following separation, Stage 26 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

<u>System Resource/Functionality</u>

Stage 25 functionality, plus:

- No additional functionality added on this flight

Resources Available:	*Power:*	*47,200 W*	
	Thermal:	*TBD*	
	EVA:	*0 crew-hours*	
Resources Required:	*Power:*	*13,392 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		4,902 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*0 crew-hours*	

Table 5.26.1-1 Stage 26 - Flight UF-6 Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
MPLM		10705
ISPRs	13000	
subtotal	**13000**	**10705**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-1324
APCU-I	714	
ROFU	450	
Misc. hardware	160	
	1324	
Variable Shuttle Consumables		-3033
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	330	
5th N2 tanks (@128 lbs/N2)	128	
5th Cryo Tank & Fluid	1575	
	3033	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1120
Maintenance Reserve		-1010
Total Shuttle Lift Capability		**24664**

Mission Flight Margin		**959**

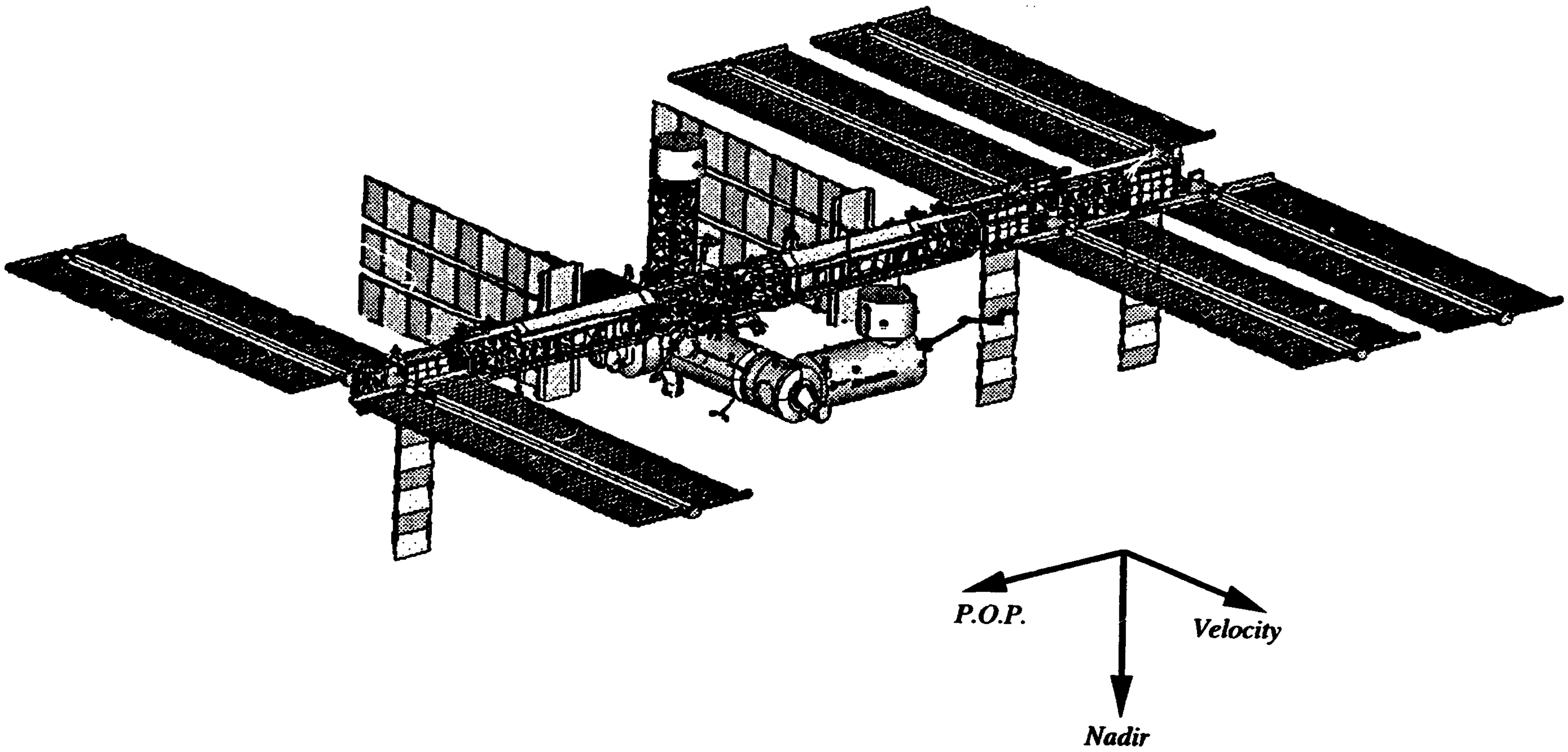


Figure 5.26.2–1 Stage 26 Configuration

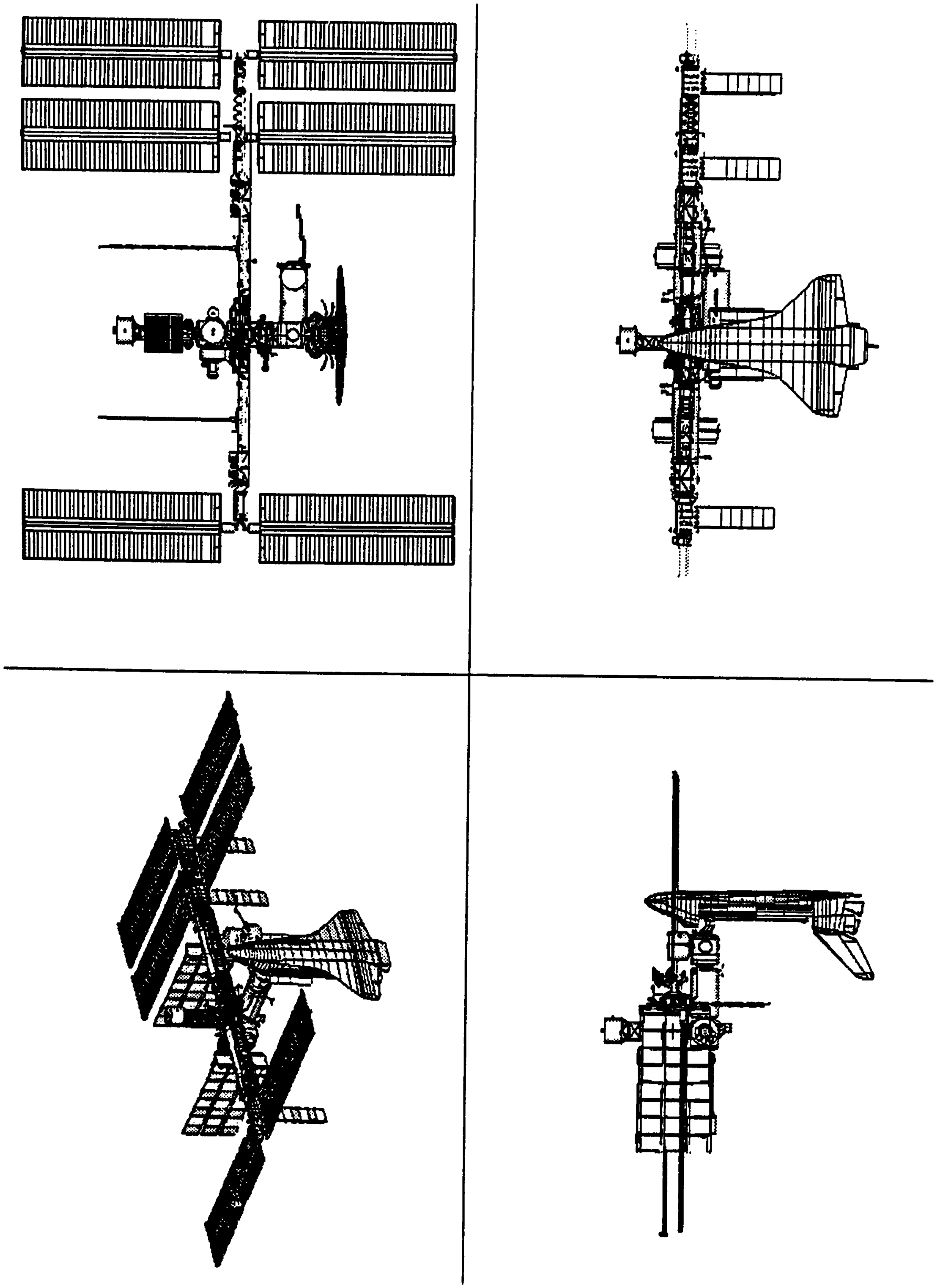


Figure 5.26.2-2 Stage 26 Configuration with Shuttle

5.26.4 Stage 26, Flight UF-6 Performance Characteristics

Stage 26, Flight UF-6 is assembled at a 230 n.mi. altitude in an LVLH flight mode with 3 pair of double axis articulating PV arrays. The nominal launch date is April, 2002.

Stage 26 in a +2σ atmosphere (solar flux = 158.1, geomagnetic index = 21.6) has a flight attitude of yaw = 0.0, pitch = 2.7, and roll = -0.7. The steady state microgravity environment is depicted in figure 5.26.4-1. Table 5.26.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 5 ISPR racks within the 1 μg environment.

Table 5.26.4-1 Stage 26 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.3
LAS-2	ISPR	1.3
LAS-3	ISPR	1.3
LAS-4	ISPR	1.4
LAS-5	SYS	1.4
LAS-6	SYS	1.4
LAF-1	SYS	1.8
LAF-2	SYS	1.8
LAF-3	SYS	1.8
LAF-4	SYS	1.9
LAF-5	SYS	1.9
LAF-6	SYS	1.9
LAP-1	ISPR	1.2
LAP-2	ISPR	1.2
LAP-3	ISPR	1.2
LAP-4	ISPR	1.2
LAP-5	SYS	1.2
LAP-6	SYS	1.3
LAC-1	ISPR	0.7
LAC-2	ISPR	0.7
LAC-3	ISPR	0.8
LAC-4	ISPR	0.8
LAC-5	ISPR	0.8
LAC-6	SYS	0.8

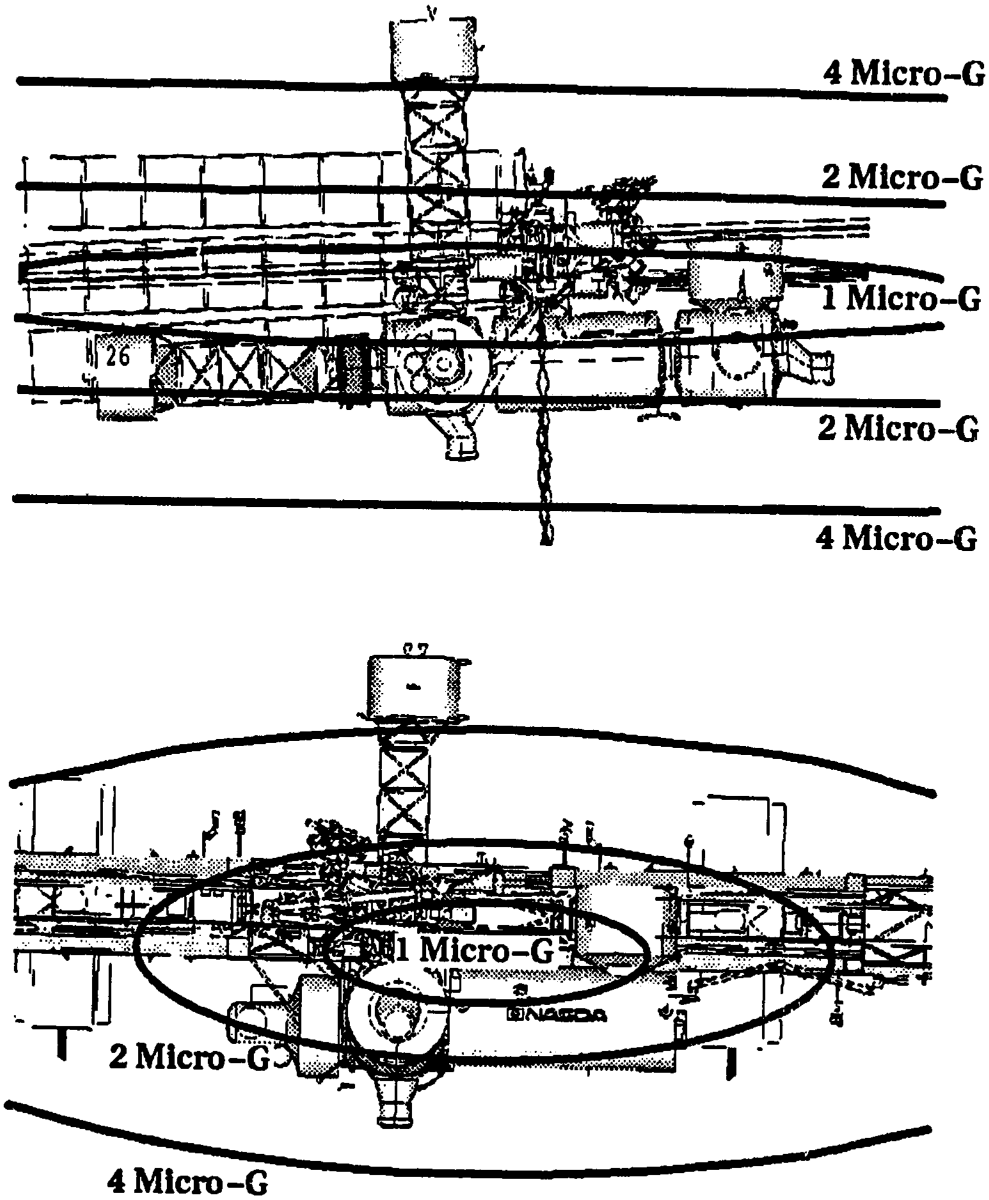


Figure 5.26.4-1 Stage 26 steady-state microgravity environment contours.

Table 5.26.4-2 summarizes the reboost lifetime characteristics of Stage 26 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 10.8 lbs/ft^2. The reboost is performed using the aft bus which currently has a reboost efficiency of 100%, while the zenith bus has fully expended its propellant load. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.26.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	238	1,483	2,585	-365	218

The control charateristics of Stage 26 are identical to Stage 25 in the design atmosphere.

5.26.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

This stage does not provide a good microgravity environment.

5.27 Stage 27 Flight Characterization

5.27.1 Stage 27 - Flight 2J/A Shuttle Flight Manifest

The second joint Japanese-American assembly mission delivers the JEM Exposed Facility and support equipment. Table 5.27.1-1 lists the Shuttle Flight Manifest for Stage 27 - Flight 2J/A. The total mass of the station hardware to orbit is 14540 lbs and FSE mass of 4475. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 26216 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 7201 lbs.

5.27.2 Stage 27 Configuration

Figure 5.27.2-1 displays the isometric view of Stage 27 after the Shuttle departs and the scheduled assembly is completed. Figure 5.27.2-2 shows the front, side, top and isometric views of Stage 27 with the Shuttle attached.

5.27.3 Flight 2 J/A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 26 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 2 J/A is a 7 day mission with 1 EVA. The SRMS unberths the JEM EF from the Shuttle payload bay and hands off the element to the SSRMS. The JEM EF is berthed to the JEM PM by attaching it to the JEM PM/EF Berthing Mechanism. The SSRMS removes the ULC, containing the PV battery sets and BCDU, from the payload bay and attaches it to the MBS. The 2 PV battery sets / BCDUs are then installed on the P6 IEA on the next day, utilizing the SSRMS/SPDM. The JEM ELM-ES is unberthed from the Shuttle payload bay by the SRMS and handed-off to the SSRMS. The element is subsequently attached to the JEM EF. Upon completing the installation of the 2 PV battery sets via the SPDM, the SSRMS returns ULC to the payload bay. All JEM elements and JEM EF payloads are checked out and activated.

Following separation, Stage 27 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 26 functionality, plus:

- Activates JEM EF and JEM ELM-ES
- JEM EF payloads capability
- JEM unpressurized logistics capability
- Full PV battery complement at P6

Resources Available:	*Power:*	*56,800 W*	
	Thermal:	*TBD*	
	EVA:	*12 crew-hours*	
Resources Required:	*Power:*	*13,412 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		5,600 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*6:30 crew-hours*	

Table 5.27.1-1 Stage 27 - Flight 2J/A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
JEM EF	8927	
JEM ELM-ES	1761	
JEM ES Payloads	1984	
ULC-A		2675
DDC-A		1540
2 PV battery sets (on ULC)	1868	
subtotal	**14540**	**4475**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-1980
Additional Attach Hardware	990	
Additional Attach Hardware	990	
	1980	
Variable Shuttle Consumables		-55
Food & Gear (-55 lbs/day over 6)	55	
	55	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1120
Maintenance Reserve		-1780
Total Shuttle Lift Capability		**26216**

Mission Flight Margin		**7201**

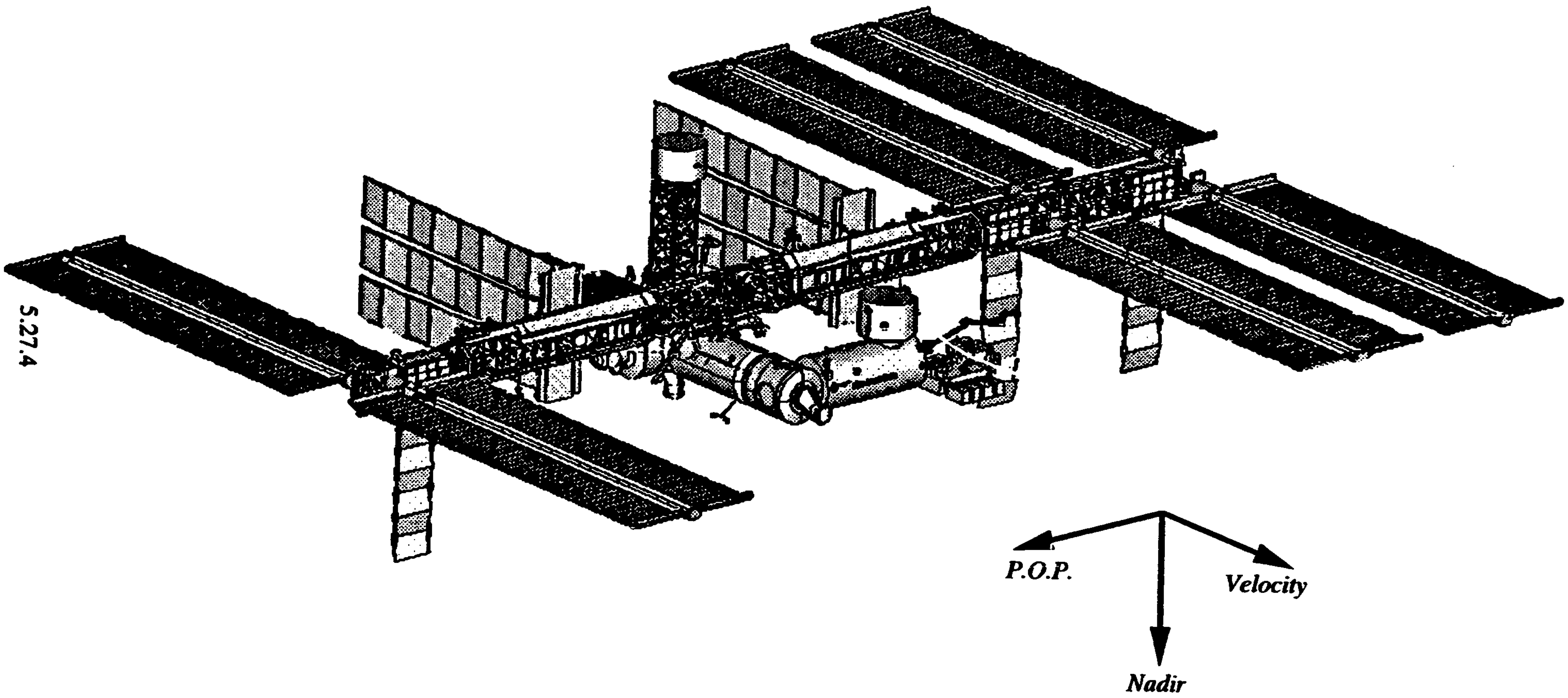


Figure 5.27.2–1 Stage 27 Configuration

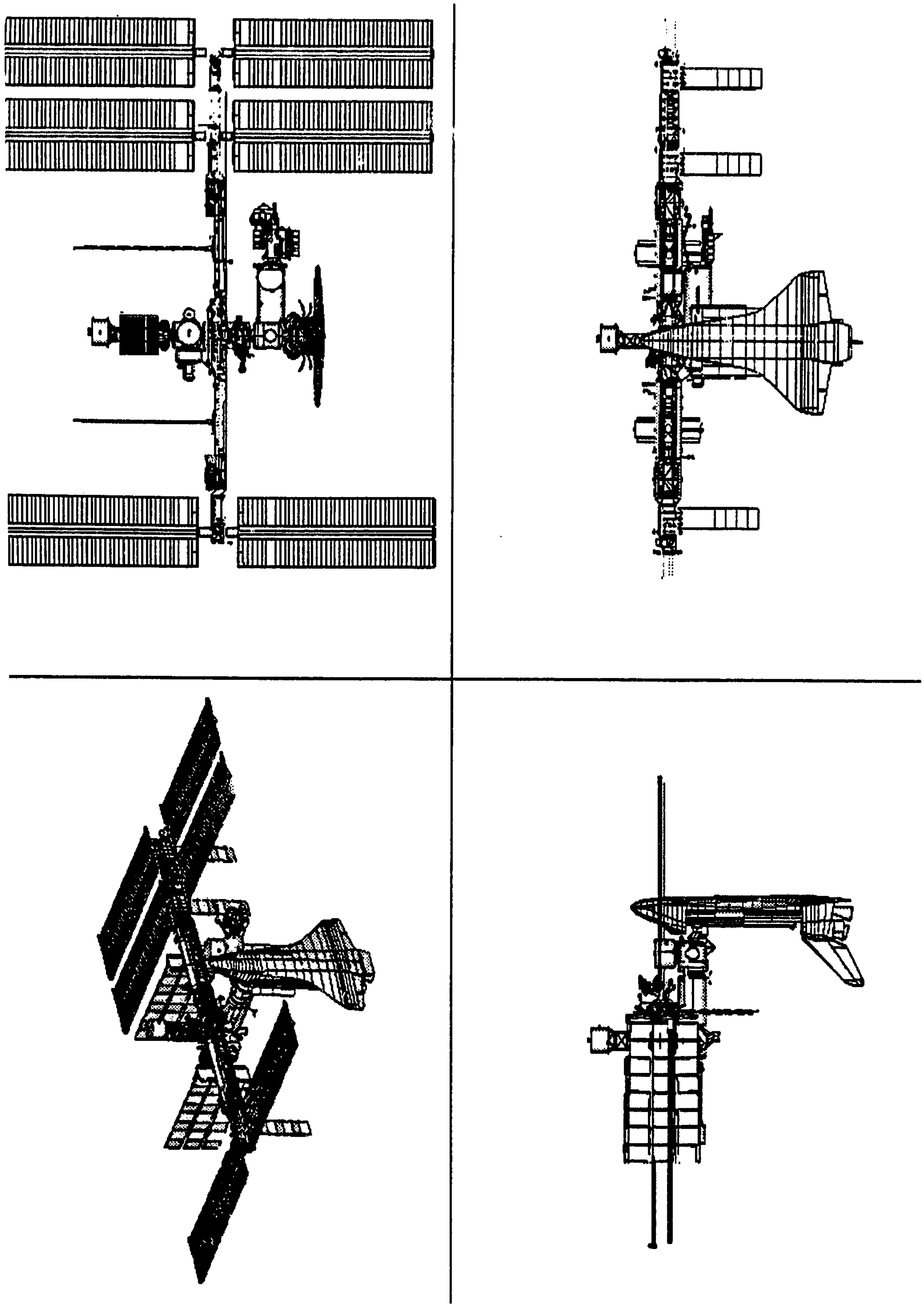


Figure 5.27.2-2 Stage 27 Configuration with Shuttle

5.27 Stage 27, Flight 2J/A Performance Characteristics

Stage 27, Flight 2J/A is assembled at a 230 n.mi. altitude in an LVLH flight mode with 3 pair of double axis articulating PV arrays. The nominal launch date is June, 2002.

Stage 27 in a +2σ atmosphere (solar flux = 152.7, geomagnetic index = 22.0) has a flight attitude of yaw = 0.0, pitch = 4.8, and roll = 0.0. The steady state microgravity environment is depicted in figure 5.27.4-1. Table 5.27.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 5 ISPR racks within the 1 μg environment.

Table 5.27.4-1 Stage 27 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.2
LAS-2	ISPR	1.3
LAS-3	ISPR	1.3
LAS-4	ISPR	1.4
LAS-5	SYS	1.4
LAS-6	SYS	1.5
LAF-1	SYS	1.7
LAF-2	SYS	1.8
LAF-3	SYS	1.8
LAF-4	SYS	1.8
LAF-5	SYS	1.8
LAF-6	SYS	1.9
LAP-1	ISPR	1.1
LAP-2	ISPR	1.1
LAP-3	ISPR	1.1
LAP-4	ISPR	1.2
LAP-5	SYS	1.2
LAP-6	SYS	1.3
LAC-1	ISPR	0.7
LAC-2	ISPR	0.7
LAC-3	ISPR	0.8
LAC-4	ISPR	0.8
LAC-5	ISPR	0.8
LAC-6	SYS	0.9

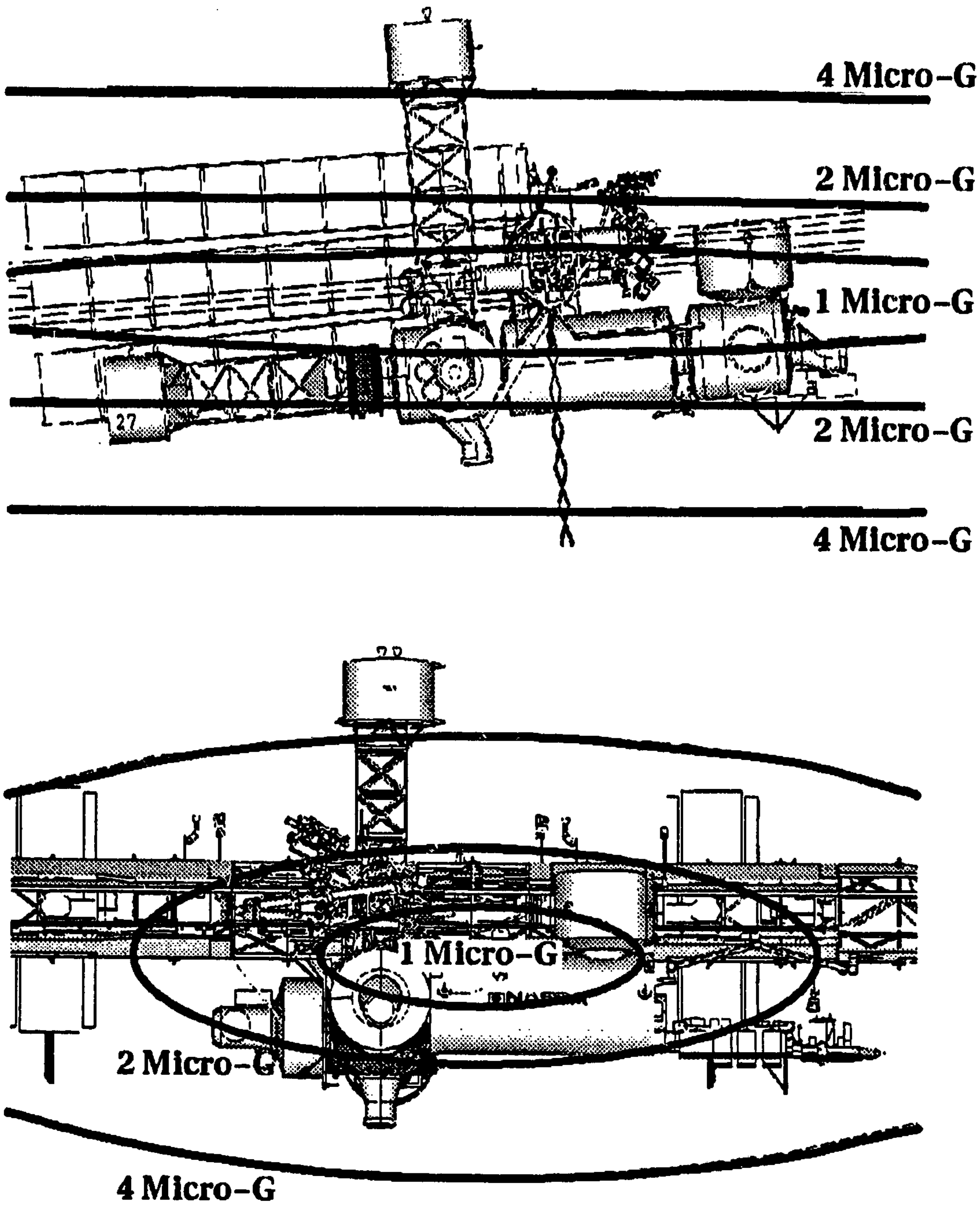


Figure 5.27.4-1 Stage 27 steady-state micrograviry environment contours.

Table 5.27.4-2 summarizes the reboost lifetime characteristics of Stage 27 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 11.3 lbs/ft^2. The reboost is performed using the aft bus which currently has a reboost efficiency of 100%, while the zenith bus has fully expended its propellant load. For this stage there is insufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.27.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	236	1,107	1,478	-365	235

The control characteristics of Stage 27 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.27.4-2. Table 5.27.4-3 summarizes the control characteristics depicted in the plots.

Table 5.27.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	3.5 degrees	3.2 degrees	-0.5 degrees	± 1.0 degrees	11,600 N-m-s
w/STS	23.0 degrees	43.4 degrees	-4.0 degrees	± 1.9 degrees	11,300 N-m-s

The control characteristics of Stage 27 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.27.4-3. Table 5.27.4-3 summarizes the control characteristics depicted in the plots.

5.27.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

For this stage there is insufficient propellant reserve on the bus to meet the skip cycle contingency reboost requirement.

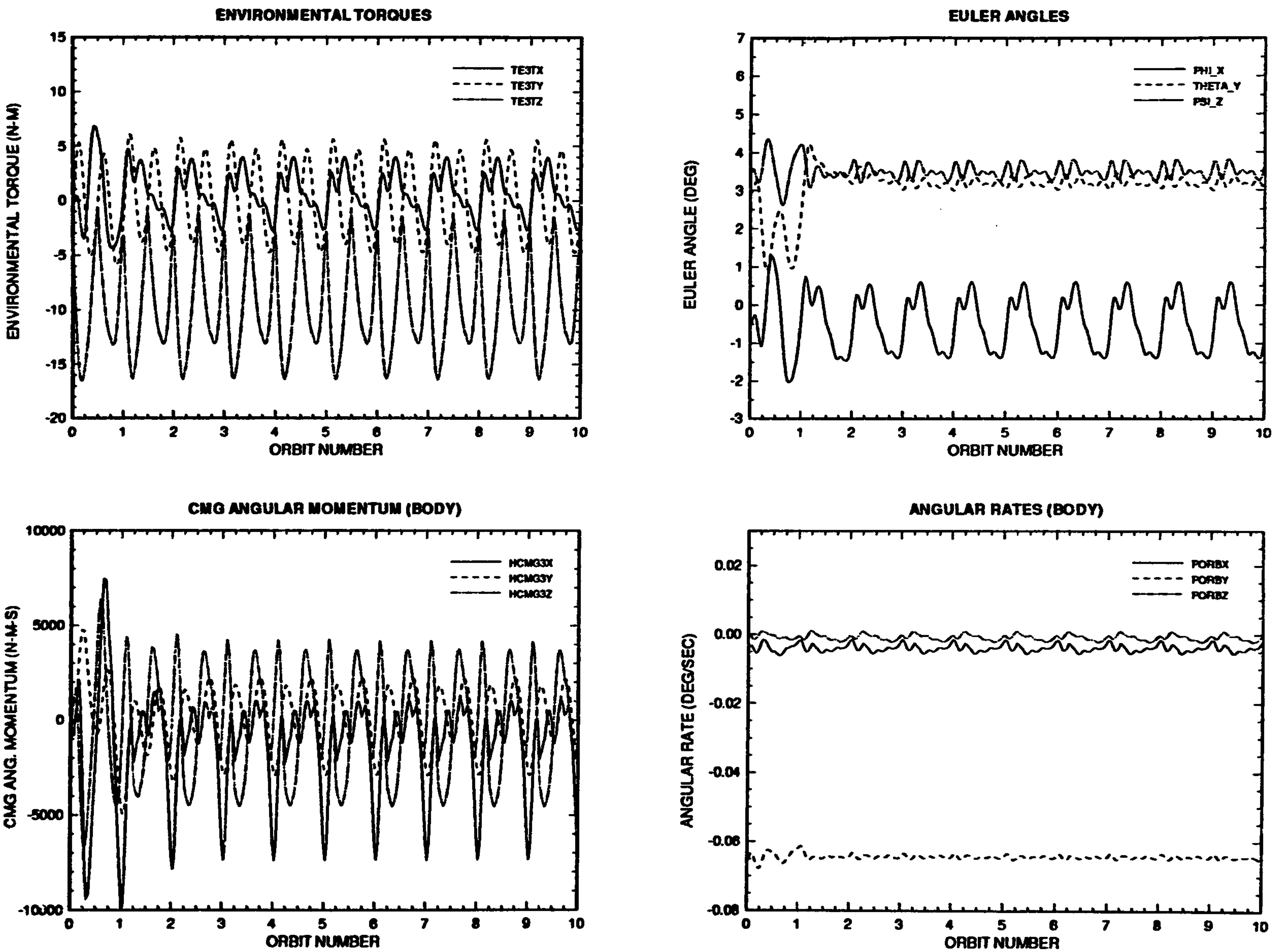


Figure 5.27.4-2 Stage 27 control plots with Shuttle attached.

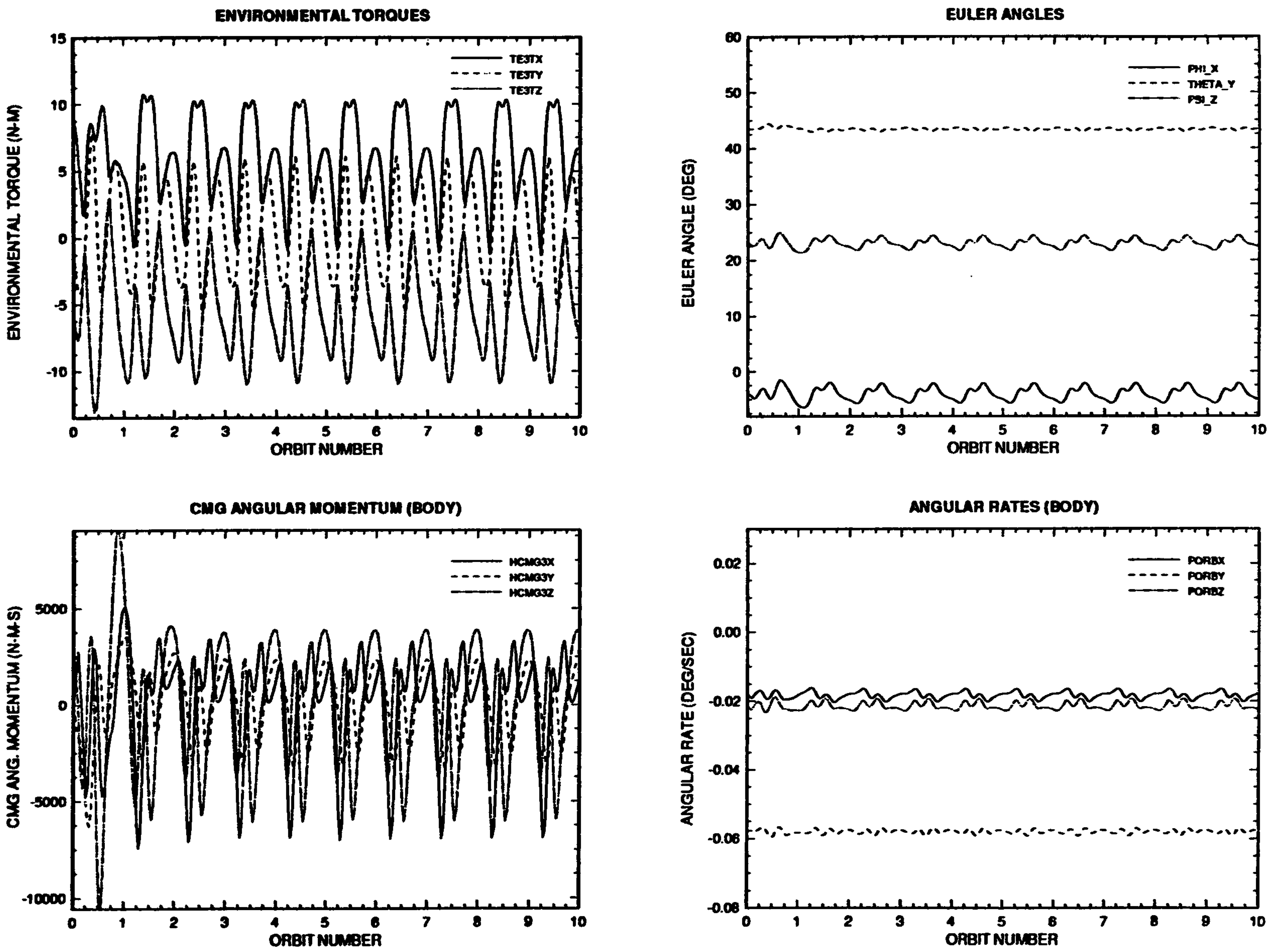


Figure 5.27.4-3 Stage 27 control plots with Shuttle attached.

5.28 Stage 28 Flight Characterization

5.28.1 Stage 28 - Flight 15A Shuttle Flight Manifest

The STS delivers the S6 truss segment. Table 5.28.1-1 lists the Shuttle Flight Manifest for Stage 28 - Flight 15A. The total mass of the station hardware to orbit is 26886 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 29092 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 2206 lbs.

5.28.2 Stage 28 Configuration

Figure 5.28.2-1 displays the isometric view of Stage 28 after the Shuttle departs and the scheduled assembly is completed. Figure 5.28.2-2 shows the front, side, top and isometric views of Stage 28 with the Shuttle attached.

5.28.3 Flight 15A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 27 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 15A is a 9 day mission with 3 EVAs. Installation of S6 begins with the SSRMS unberthing S6 from the Shuttle payload bay. The SSRMS handsoff the element to the SRMS, and then the SSRMS relocates to the MBS PDGF. Following a hand-off of the element back to the SSRMS, it is berthed to the POA on the MBS. The SSRMS then positions S6 for attaching it to S5. EVA umbilical connections complete the installation of S6. Subsequently, the stowed ETCS radiator on P6 is relocated to S6 to function as the S6 PV radiator, the upper and lower PV arrays and the newly installed IEA radiator are deployed and activated. SSRMS/EVA installs the S5/S6 MT/CETA rails.

Following separation, Stage 28 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

<u>System Resource/Functionality</u>

Stage 27 functionality, plus:

- Fourth solar Power Module (S6) activated w/ 4 batteries per channel

Resources Available:	*Power:*	*69,700 W*	
	Thermal:	*TBD*	
	EVA:	*36 crew-hours*	
Resources Required:	*Power:*	*13,392 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		5,600 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*35:20 crew-hours*	

Table 5.28.1-1 Stage 28 - Flight 15A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
S6 TRUSS SEGMENT	9482	
BG DEPLOYED	1338	
IEA BATTERIES (4 Battery sets)	4968	
S5/S6 MT RAILS	735	
S6 PV SPACER	5072	
SOA PVA DEPLOYED	2646	
SOF PVA DEPLOYED	2646	
subtotal	**26886**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-238
Variable Shuttle Consumables		-421
Food & Gear (-55 lbs/day over 6)	165	
5th & 6th N2 tanks (@128 lbs/N2)	256	
	421	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-400
Total Shuttle Lift Capability		**29092**

Mission Flight Margin		**2206**

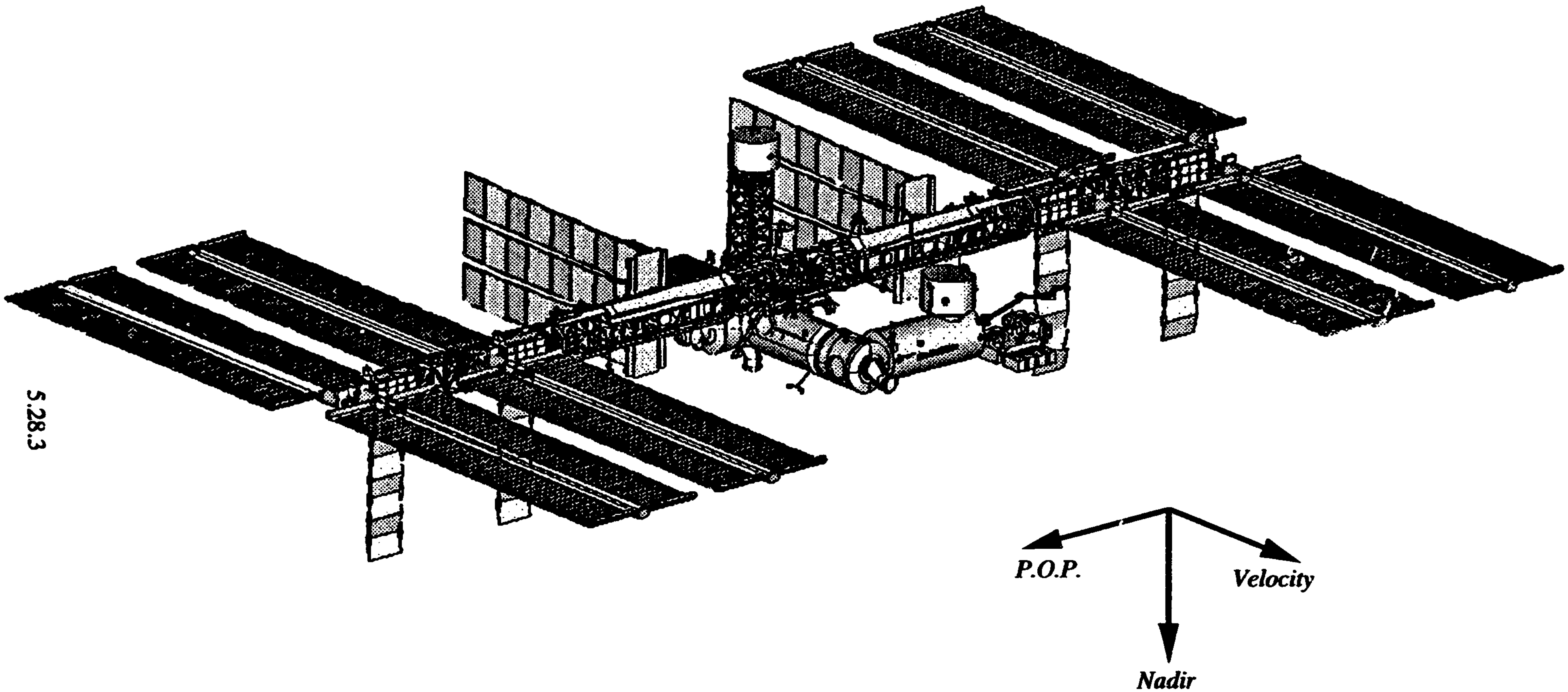


Figure 5.28.2-1 Stage 28 Configuration

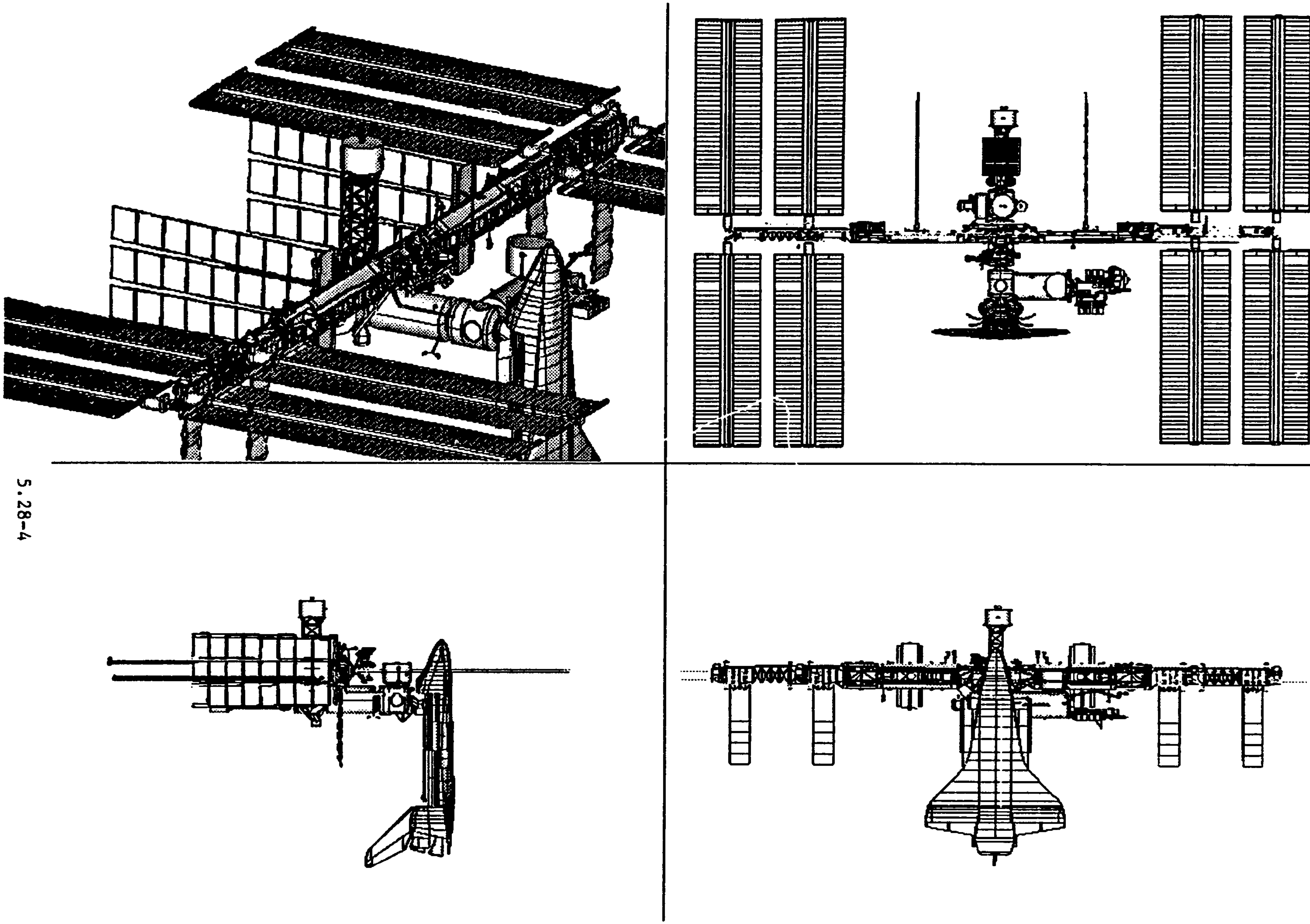


Figure 5.28.2-2 Stage 28 Configuration with Shuttle

5.28.4 Stage 28, Flight 15A Performance Characteristics

Stage 28, Flight 15A is assembled at a 230 n.mi. altitude in an LVLH flight mode with 4 pairs of double axis articulating PV arrays. The nominal launch date is August, 2002.

Stage 28 in a +2σ atmosphere (solar flux = 148.1, geomagnetic index = 22.2) has a flight attitude of yaw = -1.9, pitch = 4.6, and roll = 0.3. The steady state microgravity environment is depicted in figure 5.28.4-1. Table 5.28.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 5 ISPR racks within the 1 μg environment.

Table 5.28.4-1 Stage 28 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.1
LAS-2	ISPR	1.2
LAS-3	ISPR	1.2
LAS-4	ISPR	1.2
LAS-5	SYS	1.3
LAS-6	SYS	1.3
LAF-1	SYS	1.7
LAF-2	SYS	1.7
LAF-3	SYS	1.7
LAF-4	SYS	1.8
LAF-5	SYS	1.8
LAF-6	SYS	1.9
LAP-1	ISPR	1.1
LAP-2	ISPR	1.1
LAP-3	ISPR	1.1
LAP-4	ISPR	1.2
LAP-5	SYS	1.2
LAP-6	SYS	1.3
LAC-1	ISPR	0.5
LAC-2	ISPR	0.5
LAC-3	ISPR	0.6
LAC-4	ISPR	0.6
LAC-5	ISPR	0.7
LAC-6	SYS	0.7

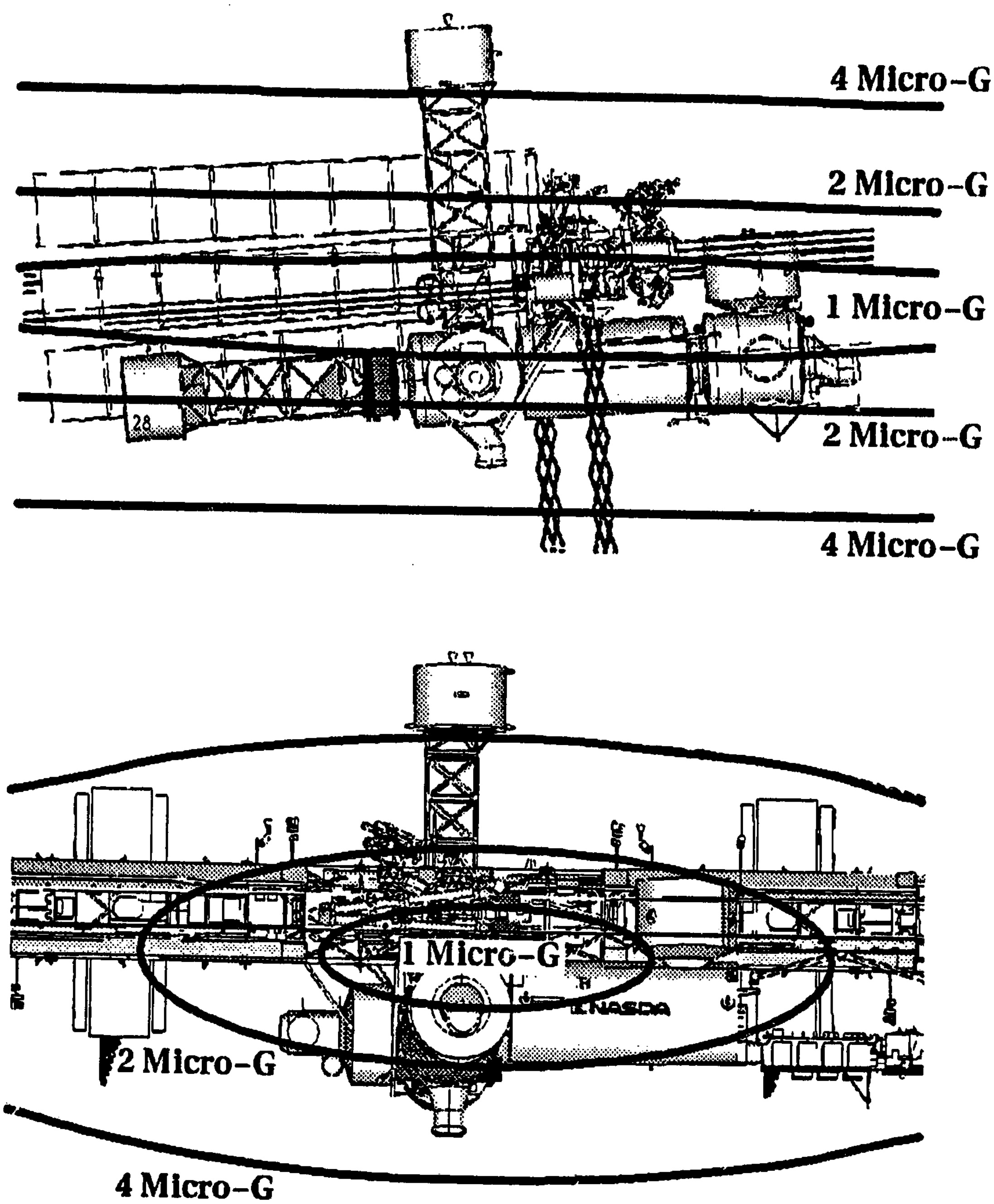


Figure 5.28.4-1 Stage 28 steady-state microgravity environment contours.

Table 5.28.4-2 summarizes the reboost lifetime characteristics of stage 28 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 9.5 lbs/ft^2. The reboost is initiated using the aft Bus, which currently has a reboost efficiency of 100%, until it expends all of its on board propellant. An additional 231 lbs of propellant is required to fully reboost the station. At this point in the assembly sequence the zenith bus has also fully expended its propellant load. For this stage there is insufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.28.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	238	1,709	-231	-365	206

The control characteristics of Stage 28 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.28.4-2. Table 5.28.4-3 summarizes the control characteristics depicted in the plots.

Table 5.28.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	-1.9 degrees	2.1 degrees	0.3 degrees	± 0.4 degrees	7800 N-m-s
w/STS	-3.3 degrees	43.8 degrees	-1.8 degrees	± 0.8 degrees	5900 N-m-s

The control characteristics of Stage 28 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.28.4-3. Table 5.28.4-3 summarizes the control characteristics depicted in the plots.

5.28.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

For this stage there is insufficient propellant reserve on the bus to meet the skip cycle contingency reboost requirement.

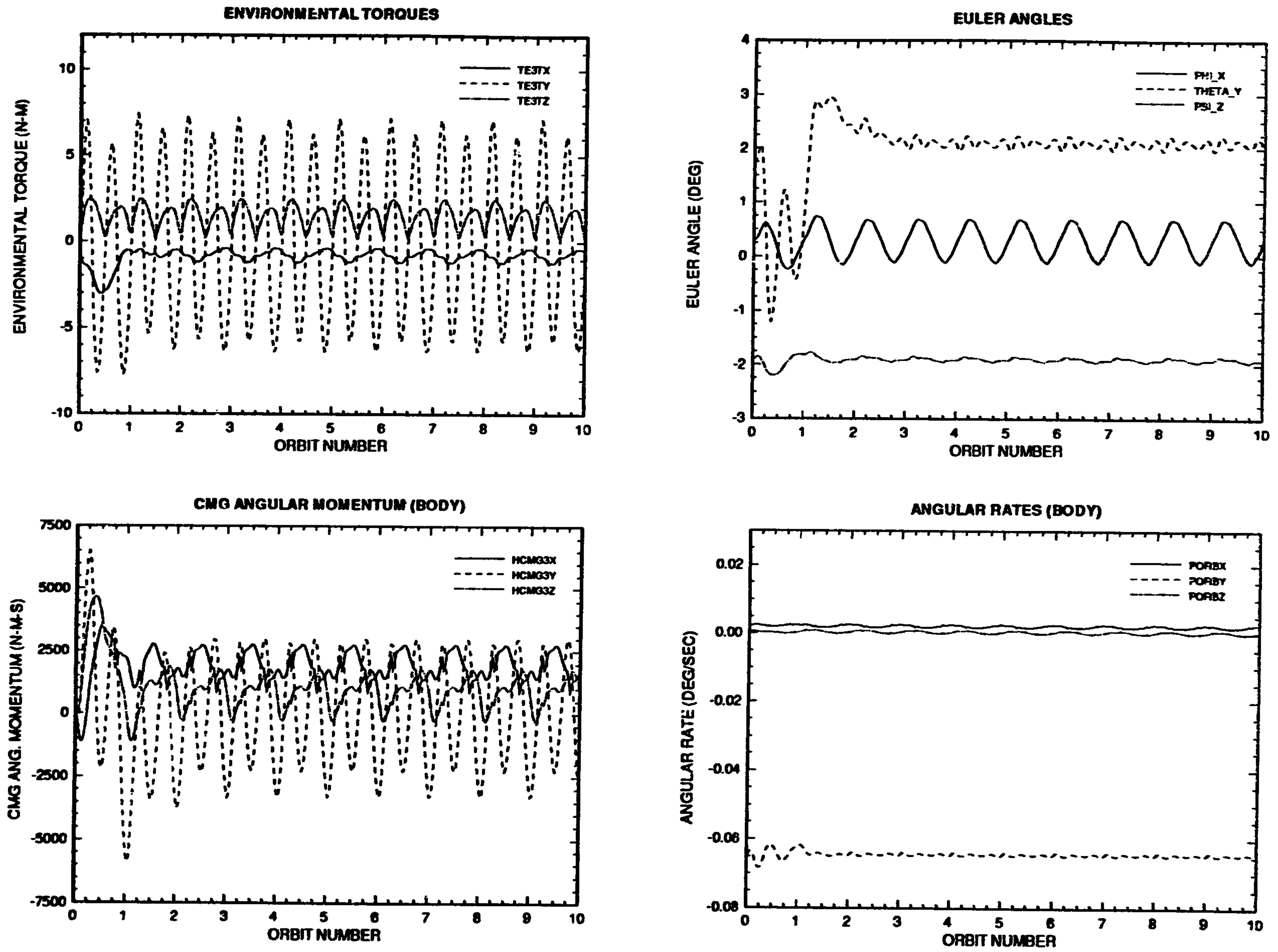


Figure 5.28.4-2 Stage 28 control plots without Shuttle attached.

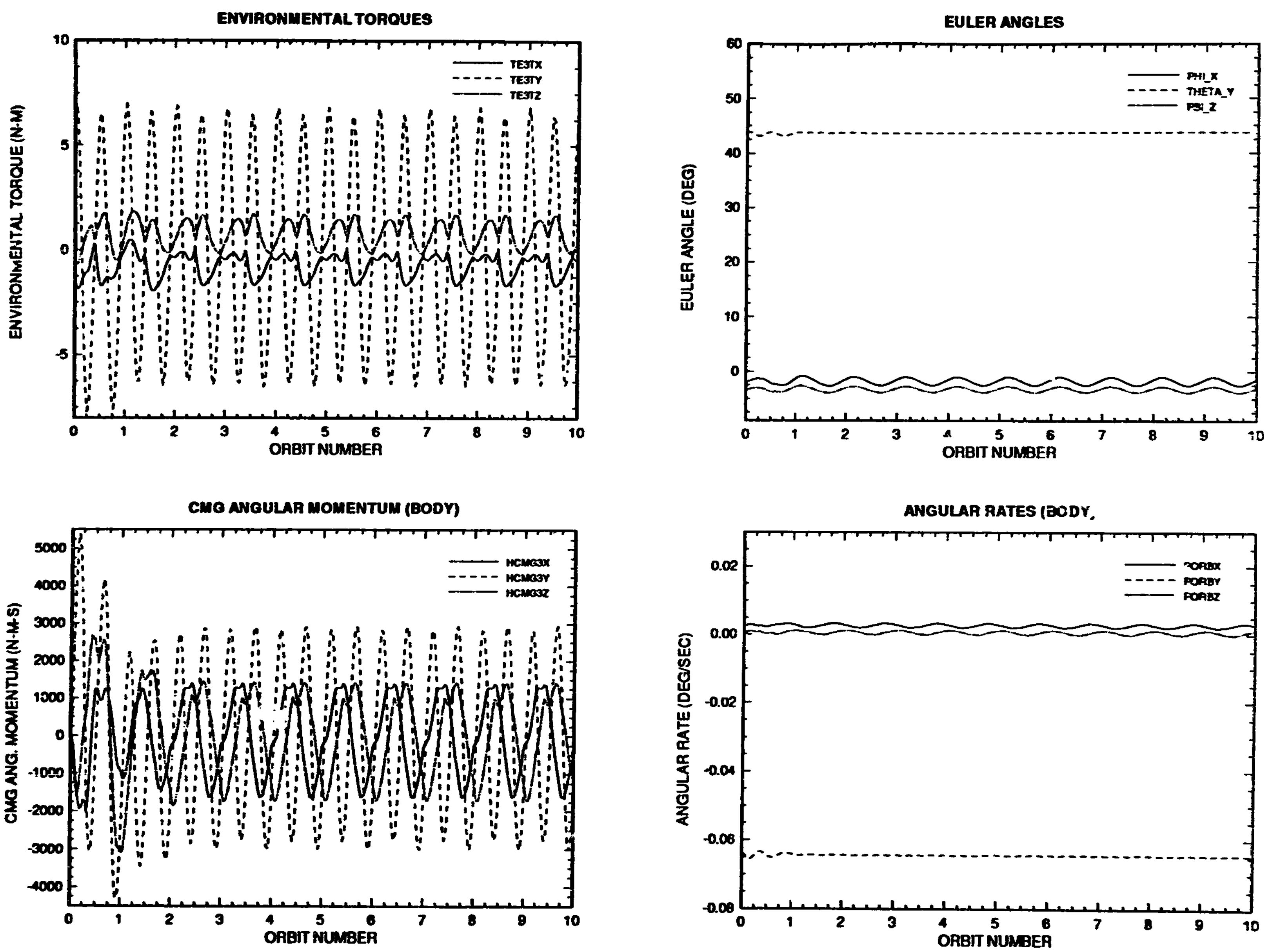


Figure 5.28.4-3 Stage 28 control plots with Shuttle attached.

5.29 Stage 29 Flight Characterization

5.29.1 Stage 29 - Flight BF-2 Flight Shuttle Manifest

This Shuttle flight provides the second Bus-1 resupply. Table 5.29.1-1 lists the Shuttle Flight Manifest for Stage 29 - Flight BF-2. The total mass of the station hardware to orbit is 25000 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 29458 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 4458 lbs.

5.29.2 Stage 29 Configuration

Figure 5.29.2-1 displays the isometric view of Stage 29 after the Shuttle departs and the scheduled assembly is completed. Figure 5.29.2-2 shows the front, side, top and isometric views of Stage 29 with the Shuttle attached.

5.29.3 Flight BF-2 Assembly Operations Description

Rendezvous of the Shuttle with the Stage 28 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight BF-2 is a 7 day mission with 0 EVAs. The purpose of this flight is to replace the Bus-1 which is attached to the stinger located on the Z1 truss (the "zenith" Bus-1). The SSRMS is repositioned on the stinger grapple fixture. The SSRMS then grapples the spent Bus-1 and hands it to the SRMS. The SSRMS remains in this position while the SRMS places the spent bus in the Shuttle cargo bay and grapples the replacement Bus-1. The Bus-1 is then handed back to the SSRMS and installed on the stinger.

Following separation, Stage 29 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

<u>System Resource/Functionality</u>

Stage 28 functionality, plus:

- Bus-1 swapped to ensure adequate fuel supply

Resources Available:	*Power:*	*69,700 W*	
	Thermal:	*TBD*	
	EVA:	*0 crew-hours*	
Resources Required:	*Power:*	*13,392 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1.180 W	*(CSA)*
		5,600 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*0 crew-hours*	

Table 5.29.1-1 Stage 29 - Flight BF-2 Flight Shuttle Manifest

Hardware	Mass (lbs)	FSE
Bus-1	25000	
subtotal	**25000**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-238
Variable Shuttle Consumables		-55
Food & Gear (-55 lbs/day over 6)	55	
	55	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-400
Total Shuttle Lift Capability		**29458**
Mission Flight Margin		**4458**

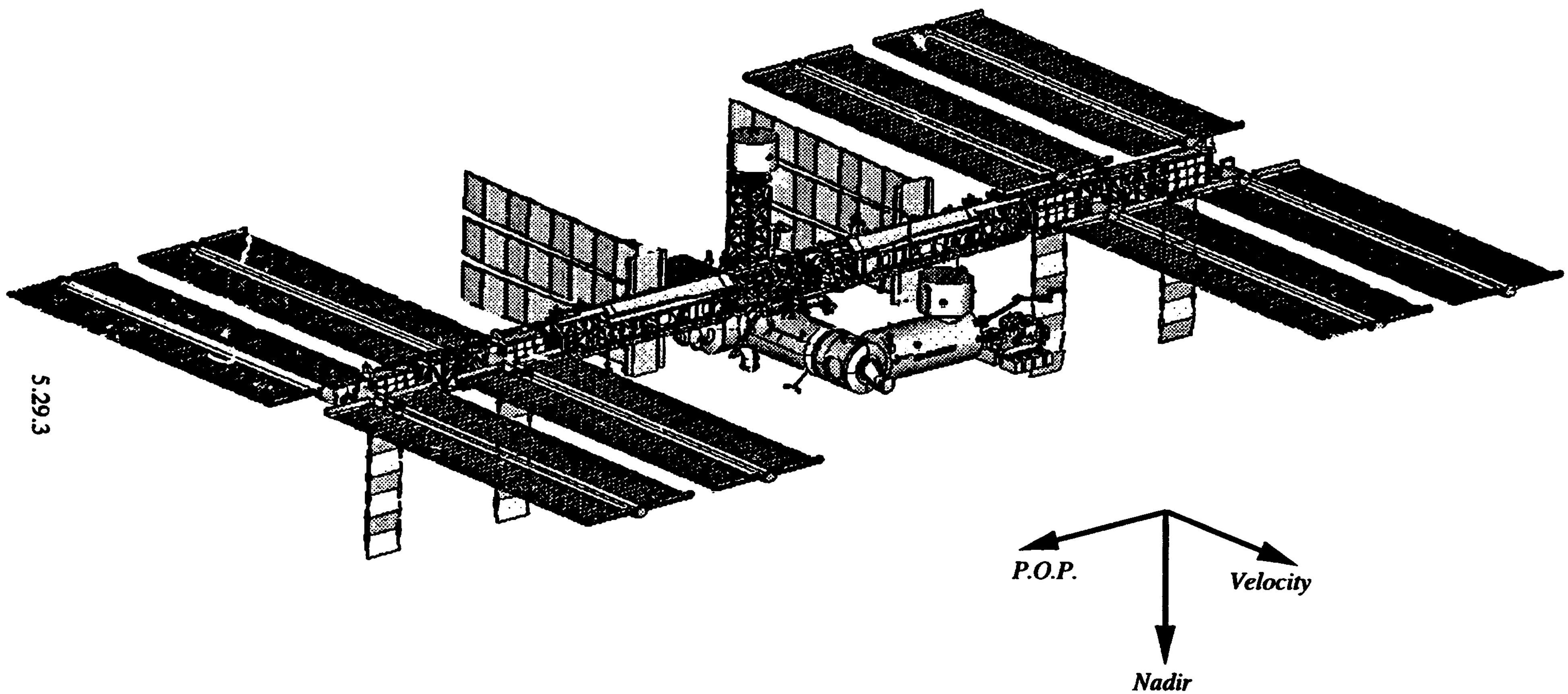


Figure 5.29.2-1 Stage 29 Configuration

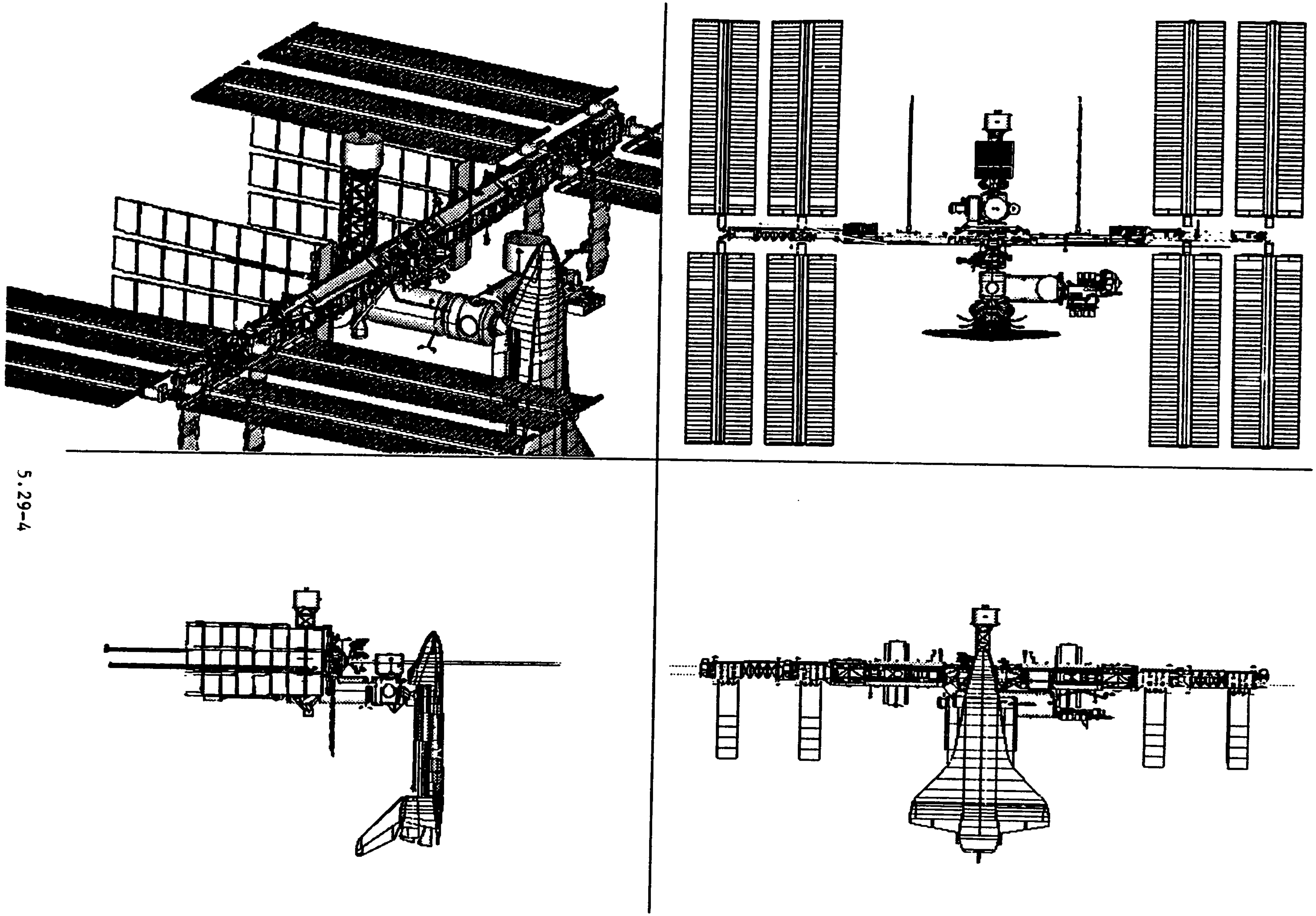


Figure 5.29.2–2 Stage 29 Configuration with Shuttle

5.29.4 Stage 29, Bus Flight 2 Performance Characteristics

Stage 29, Flight BF-2 is assembled in a 230 n.mi. altitude in an LVLH flight mode with 4 pairs of double axis articulating PV arrays. The nominal launch date is October, 2002.

Stage 29 in a +2σ atmosphere (solar flux = 141.1, geomagnetic index = 22.8) has a flight attitude of yaw = -1.9, pitch = 4.6, and roll = 0.3. The steady state microgravity environment is depicted in figure 5.29.4-1. Table 5.29.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 5 ISPR racks within the 1 μg environment.

Table 5.29.4-1 Stage 29 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.1
LAS-2	ISPR	1.2
LAS-3	ISPR	1.2
LAS-4	ISPR	1.2
LAS-5	SYS	1.3
LAS-6	SYS	1.3
LAF-1	SYS	1.7
LAF-2	SYS	1.7
LAF-3	SYS	1.7
LAF-4	SYS	1.8
LAF-5	SYS	1.8
LAF-6	SYS	1.9
LAP-1	ISPR	1.1
LAP-2	ISPR	1.1
LAP-3	ISPR	1.1
LAP-4	ISPR	1.2
LAP-5	SYS	1.2
LAP-6	SYS	1.3
LAC-1	ISPR	0.5
LAC-2	ISPR	0.5
LAC-3	ISPR	0.6
LAC-4	ISPR	0.6
LAC-5	ISPR	0.7
LAC-6	SYS	0.7

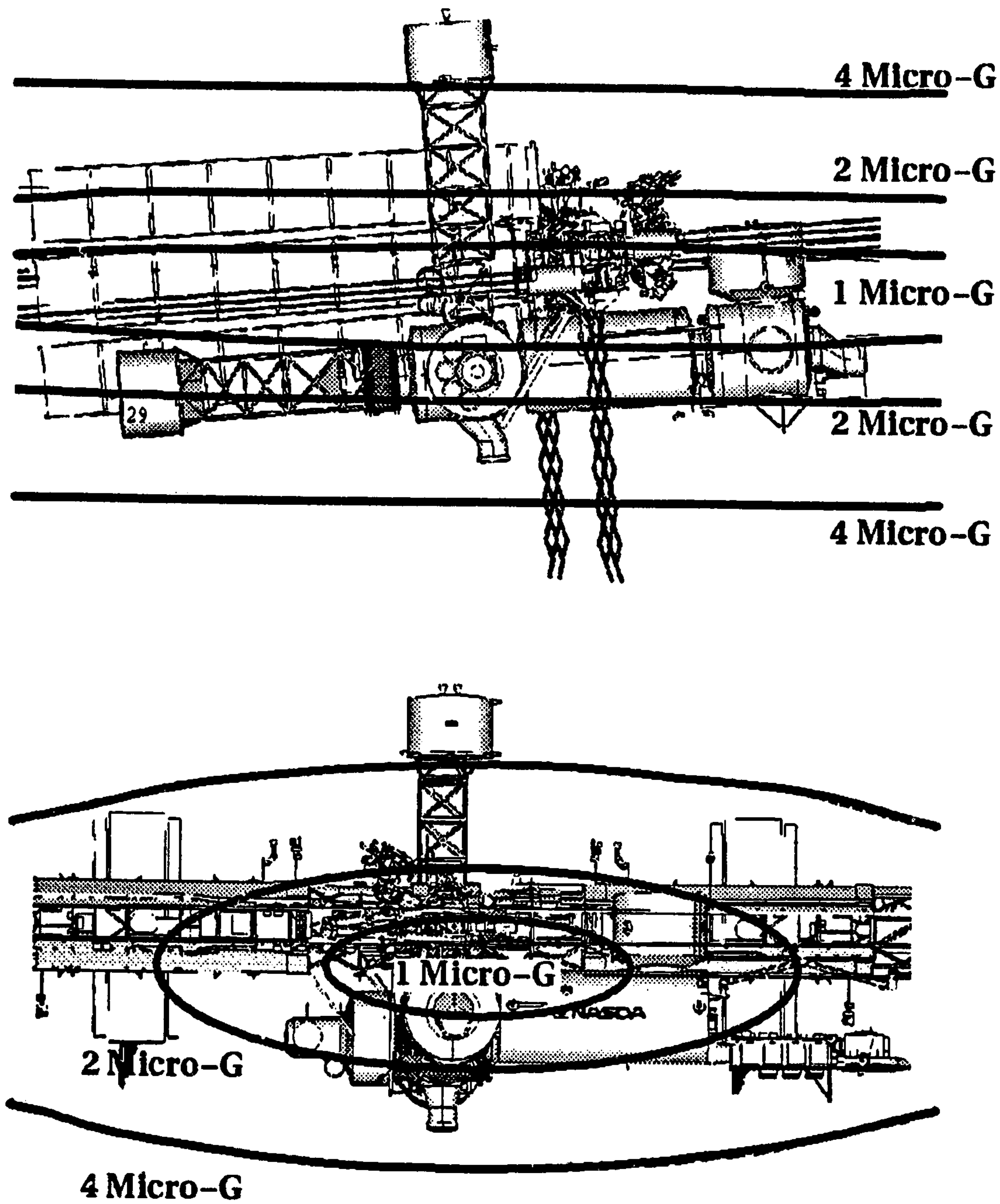


Figure 5.29.4-1 Stage 29 steady-state microgravity environment contours.

Table 5.29.4-2 summarizes the reboost lifetime characteristics of Stage 29 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 9.5 lbs/ft^2. The reboost is performed using the zenith bus which currently has a reboost efficiency of 86%, while the aft bus has fully expended its propellant load. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.29.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	239	2,058	-231	9,542	223

The control characteristics are the same as stage 28 in the design atmosphere.

5.29.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

5.30 Stage 30 Flight Characterization

5.30.1 Stage 30 - Flight UF-7 Shuttle Flight Manifest

This Shuttle flight delivers the seventh utilization flight. Table 5.30.1-1 lists the Shuttle Flight Manifest for Stage 30 - Flight UF-7. The total mass of the station hardware to orbit is ~14390 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 25294 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 199 lbs.

5.30.2 Stage 30 Configuration

Figure 5.30.2-1 displays the isometric view of Stage 30 after the Shuttle departs and the scheduled assembly is completed. Figure 5.30.2-2 shows the front, side, top and isometric views of Stage 30 with the Shuttle attached.

5.30.3 Flight UF-7 Assembly Operations Description

Rendezvous of the Shuttle with the Stage 29 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight UF-7 is a 12 day mission with 0 EVAs. The SRMS unberths the MPLM from the Shuttle payload bay and installs it on the Node 2 nadir port CBM. Upon completion of the rack exchange, the MPLM is returned to payload bay.

Following separation, Stage 30 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 29 functionality, plus:

- No additional functionality added on this flight

Resources Available:	*Power:*	*69,700 W*	
	Thermal:	*TBD*	
	EVA:	*0 crew-hours*	
Resources Required:	*Power:*	*13,392 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		5,600 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*0 crew-hours*	

Table 5.30.1-1 Stage 30 - Flight UF-7 Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
MPLM		10705
ISPRs (lab)	13500	
JEM ELM PS / US Stowage Rack 3	890	
subtotal	**14390**	**10705**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-1324
APCU-I	714	
ROFU	450	
Misc. hardware	160	
	1324	
Variable Shuttle Consumables		-3033
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	330	
5th N2 tanks (@128 lbs/N2)	128	
5th Cryo Tank & Fluid	1575	
	3033	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1100
Maintenance Reserve		-400
Total Shuttle Lift Capability		**25294**

Mission Flight Margin		**199**

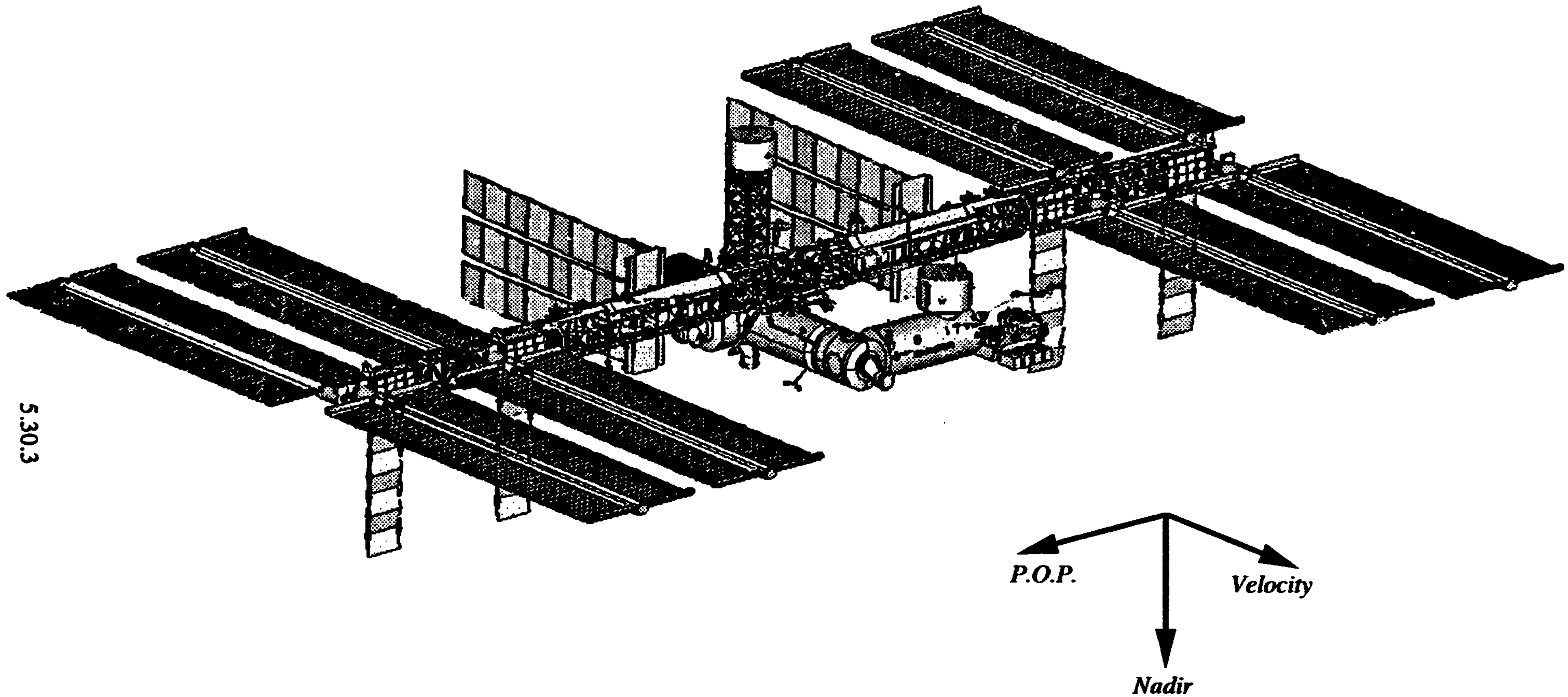


Figure 5.30.2–1 Stage 30 Configuration

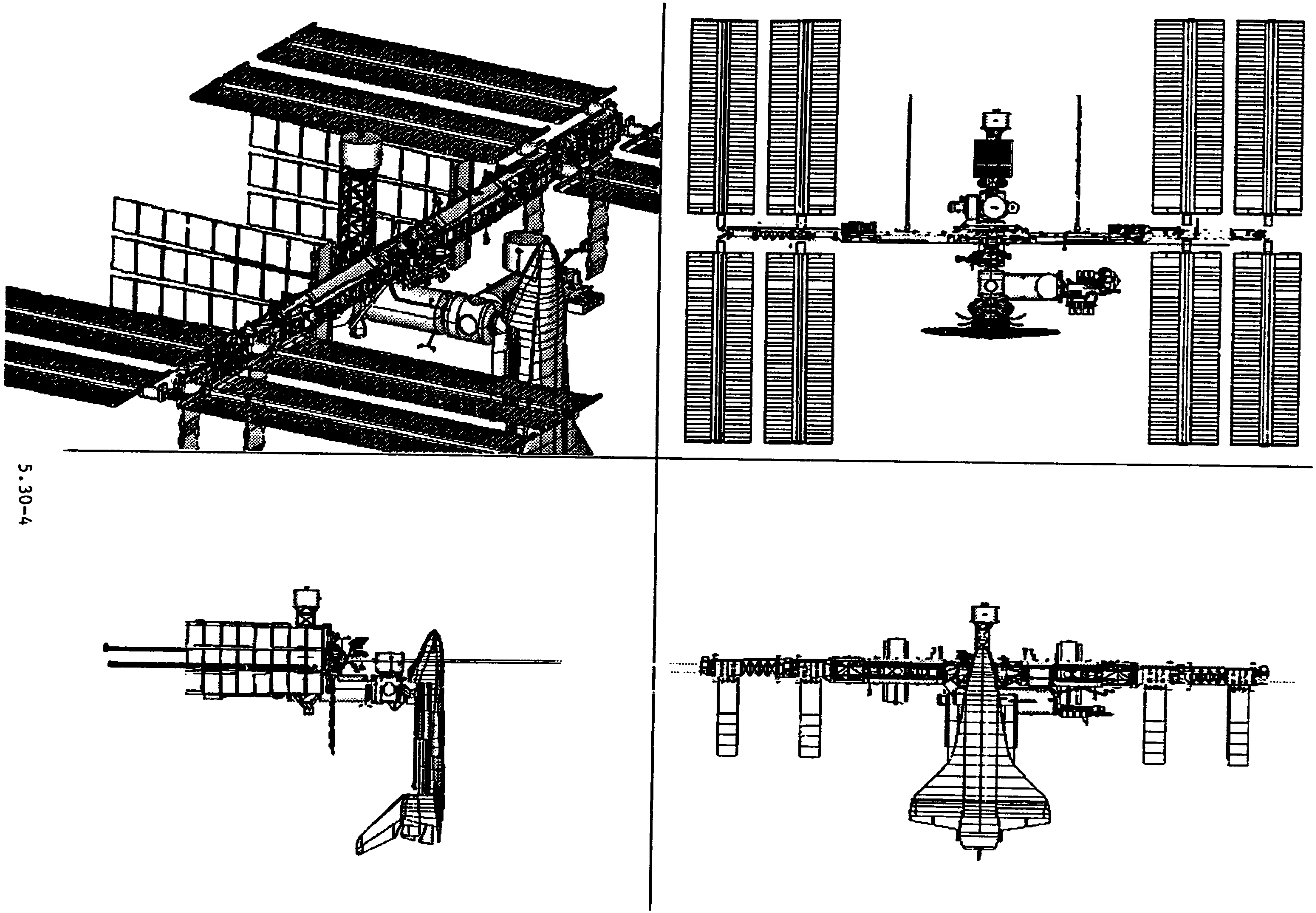


Figure 5.30.2–2 Stage 30 Configuration with Shuttle

5.30.4 Stage 30, Flight UF-7 Performance Characteristics

Stage 30, Flight UF-7 is assembled at a 230 n.mi. altitude in an LVLH flight mode with 4 pairs of double axis articulating PV arrays. The nominal launch date is December, 2002. Stage 30 in a +2σ atmosphere (solar flux = 132.4, geomagnetic index = 24.2) has a flight attitude of yaw = -1.9, pitch = 4.8, and roll = 0.3. The steady state microgravity environment is depicted in figure 5.30.4-1. Table 5.30.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 6 ISPR racks within the 1 μg environment.

Table 5.30.4-1 Stage 30 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.1
LAS-2	ISPR	1.1
LAS-3	ISPR	1.2
LAS-4	ISPR	1.2
LAS-5	SYS	1.3
LAS-6	SYS	1.3
LAF-1	SYS	1.7
LAF-2	SYS	1.7
LAF-3	SYS	1.7
LAF-4	SYS	1.8
LAF-5	SYS	1.8
LAF-6	SYS	1.9
LAP-1	ISPR	1.0
LAP-2	ISPR	1.1
LAP-3	ISPR	1.1
LAP-4	ISPR	1.2
LAP-5	SYS	1.2
LAP-6	SYS	1.2
LAC-1	ISPR	0.5
LAC-2	ISPR	0.5
LAC-3	ISPR	0.6
LAC-4	ISPR	0.6
LAC-5	ISPR	0.7
LAC-6	SYS	0.7

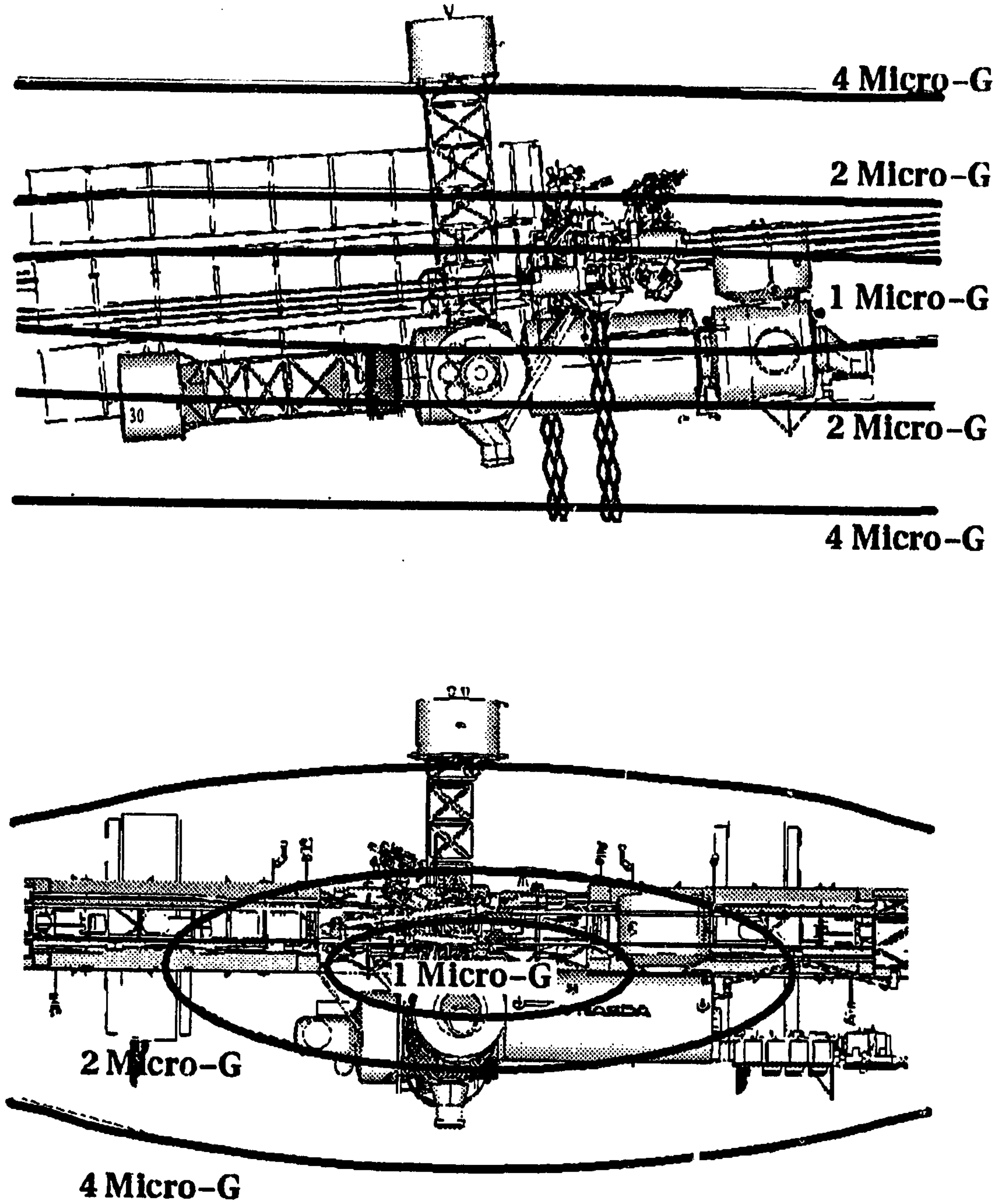


Figure 5.30.4-1 Stage 30 steady-state microgravity environment contours.

Table 5.30.4-2 summarizes the reboost lifetime characteristics of Stage 30 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 9.4 lbs/ft^2. The reboost is performed using the zenith Bus which currently has a reboost efficiency of 86%, while the aft bus has fully expended its propellant load. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.30.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	236	1,428	-231	8,113	270

The control characteristics of Stage 30 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.30.4-2. Table 5.30.4-3 summarizes the control characteristics depicted in the plots.

Table 5.30.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	-1.8 degrees	2.1 degrees	0.3 degrees	± 0.4 degrees	7800 N-m-s
w/STS	-3.4 degrees	44.0 degrees	-1.8 degrees	± 1.7 degrees	6600 N-m-s

The control characteristics of Stage 30 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (momentum emphasis) are displayed in figure 5.30.4-3. Table 5.30.4-3 summarizes the control characteristics depicted in the plots.

5.30.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

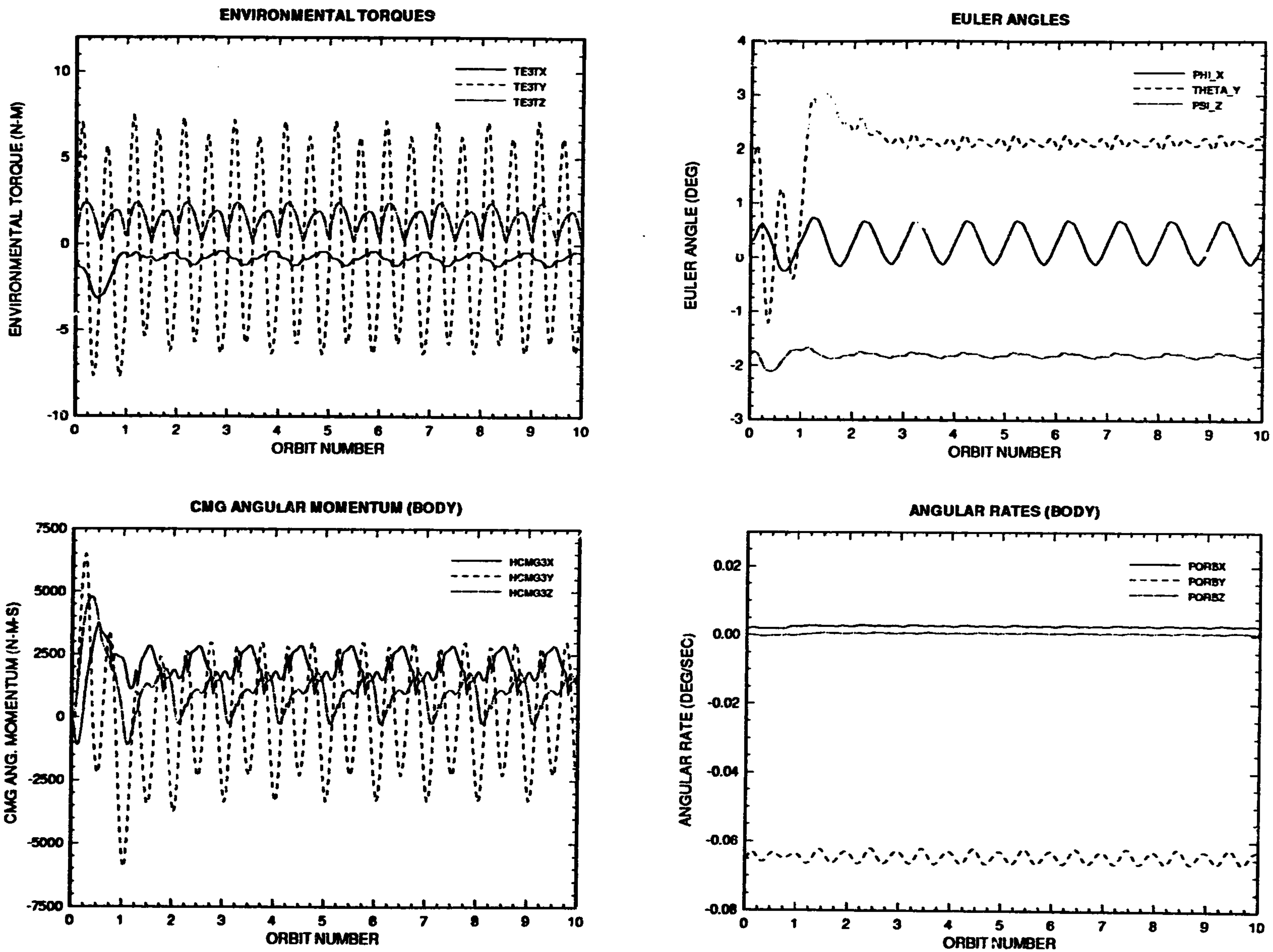


Figure 5.30.4-2 Stage 30 control plots without Shuttle attached.

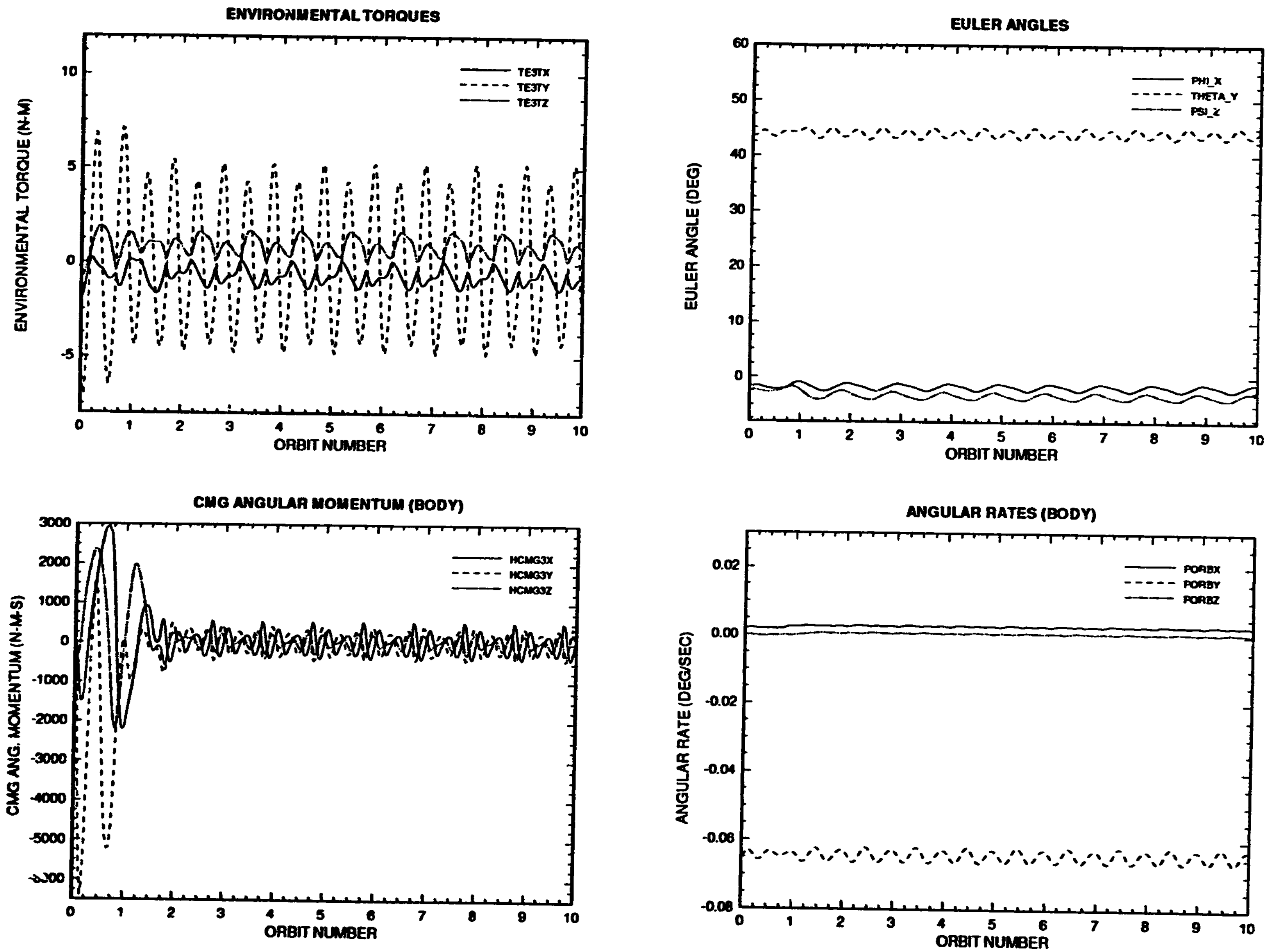


Figure 5.30.4-3 Stage 30 control plots with Shuttle attached.

5.31 Stage 31 Flight Characterization

5.31.1 Stage 31 - Flight 14A Shuttle Flight Manifest

The Shuttle delivers the centrifuge. Table 5.31.1-1 lists the Shuttle Flight Manifest for Stage 31 - Flight 14A. The total mass of the station hardware to orbit is 24255 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 25735 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 1480 lbs.

5.31.2 Stage 31 Configuration

Figure 5.31.2-1 displays the isometric view of Stage 31 after the Shuttle departs and the scheduled assembly is completed. Figure 5.31.2-2 shows the front, side, top and isometric views of Stage 31 with the Shuttle attached.

5.31.3 Flight 14A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 30 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 14A is a 9 day mission with 1 EVAs. The SRMS unberths the Centrifuge Module from the Shuttle payload bay and installs it on the Node 2 zenith port CBM. EVA crewmembers complete the installation by connecting the umbilicals to the Centrifuge Module. Assembly, activation and checkout of the centrifuge are performed by the crew prior to departure.

Following separation, Stage 31 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

<u>System Resource/Functionality</u>

Stage 30 functionality, plus:

- No additional functionality added on this flight

Resources Available:	*Power:*	*69,700 W*	
	Thermal:	*TBD*	
	EVA:	*12 crew-hours*	
Resources Required:	*Power:*	*16,691 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		5,600 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*12:00 crew-hours*	

Table 5.31.1-1 Stage 31 - Flight 14A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
Centrifuge	24255	
subtotal	**24255**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		0
Variable Shuttle Consumables		-2996
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	165	
5th & 6th N2 tanks (@128 lbs/N2)	256	
5th Cryo Tank & Fluid	1575	
	2996	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1620
Maintenance Reserve		-800
Total Shuttle Lift Capability		**25735**
Mission Flight Margin		**1480**

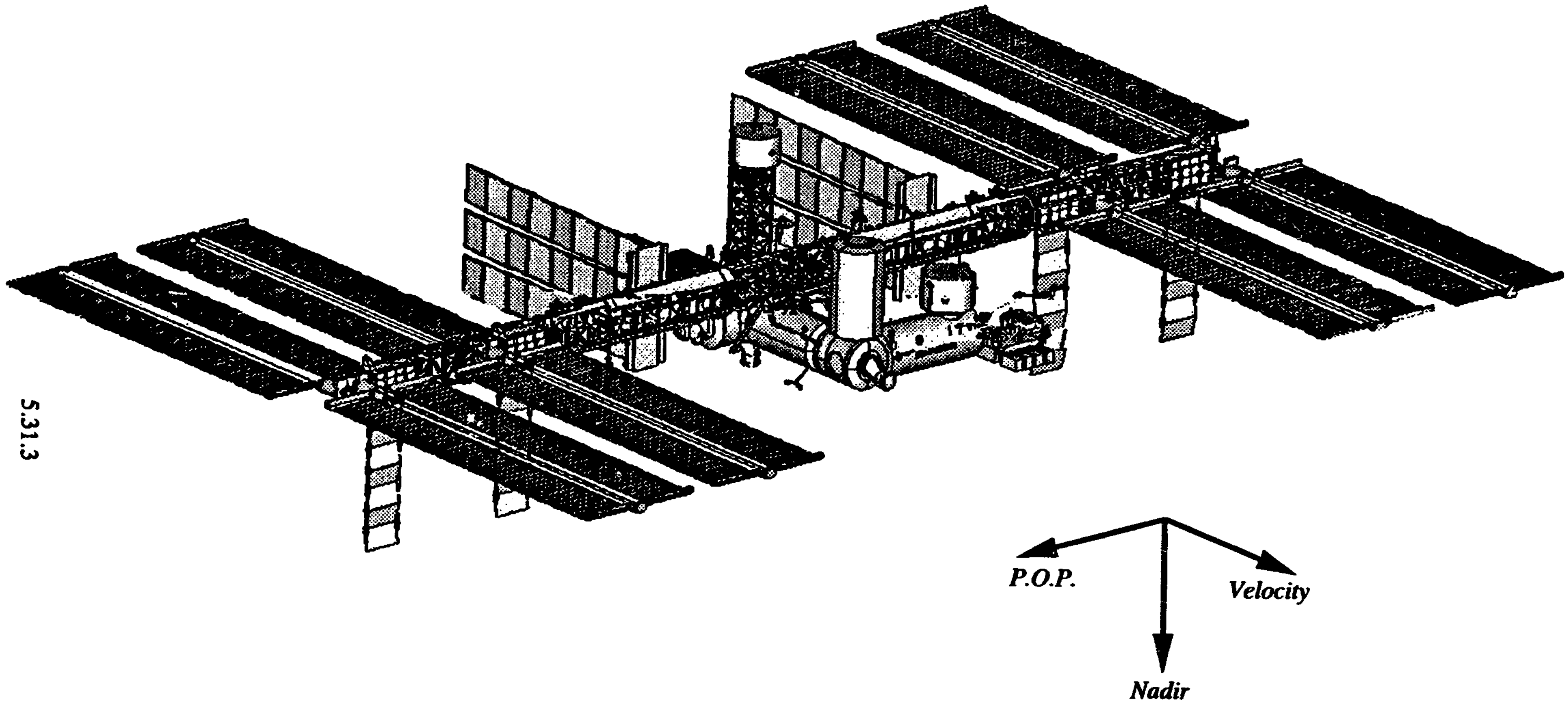


Figure 5.31.2-1 Stage 31 Configuration

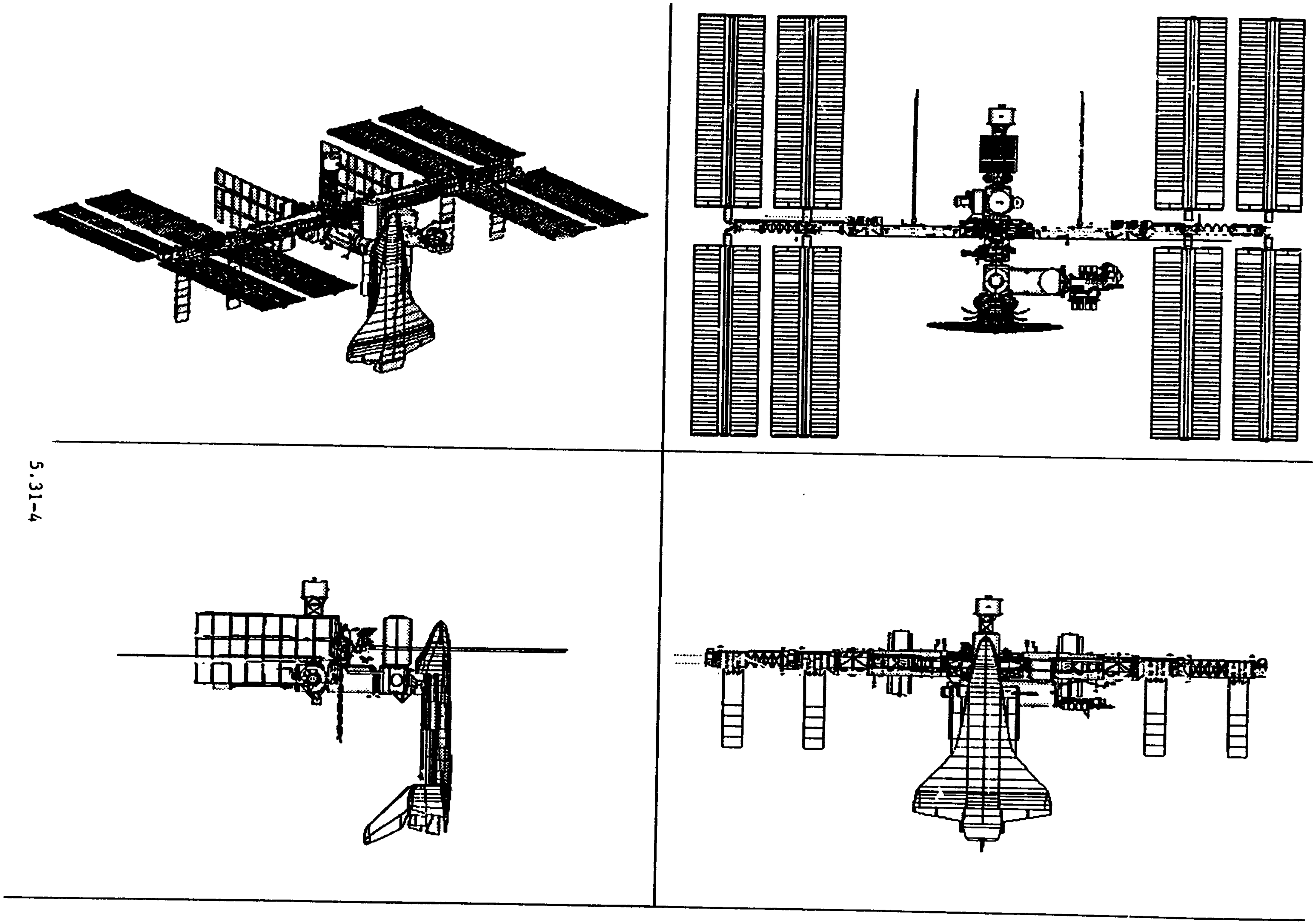


Figure 5.31.2-2 Stage 31 Configuration with Shuttle

5.31.4 Stage 31, Flight 14A Performance Characteristics

Stage 31, Flight 14A is assembled at a 230 n.mi. altitude in an LVLH flight mode with 4 pairs of double axis articulating PV arrays. The nominal launch date is February, 2003.

Stage 31 in a +2σ atmosphere (solar flux = 119.5, geomagnetic index = 25) has a flight attitude of yaw = -1.8, pitch = 2.6, and roll = 0.4. The steady state microgravity environment is depicted in figure 5.31.4-1. Table 5.31.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 5 ISPR racks within the 1 μg environment.

Table 5.31.4-1 Stage 31 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.2
LAS-2	ISPR	1.3
LAS-3	ISPR	1.3
LAS-4	ISPR	1.3
LAS-5	SYS	1.3
LAS-6	SYS	1.3
LAF-1	SYS	1.8
LAF-2	SYS	1.8
LAF-3	SYS	1.8
LAF-4	SYS	1.9
LAF-5	SYS	1.9
LAF-6	SYS	1.9
LAP-1	ISPR	1.2
LAP-2	ISPR	1.2
LAP-3	ISPR	1.2
LAP-4	ISPR	1.2
LAP-5	SYS	1.3
LAP-6	SYS	1.3
LAC-1	ISPR	0.6
LAC-2	ISPR	0.6
LAC-3	ISPR	0.6
LAC-4	ISPR	0.7
LAC-5	ISPR	0.7
LAC-6	SYS	0.7

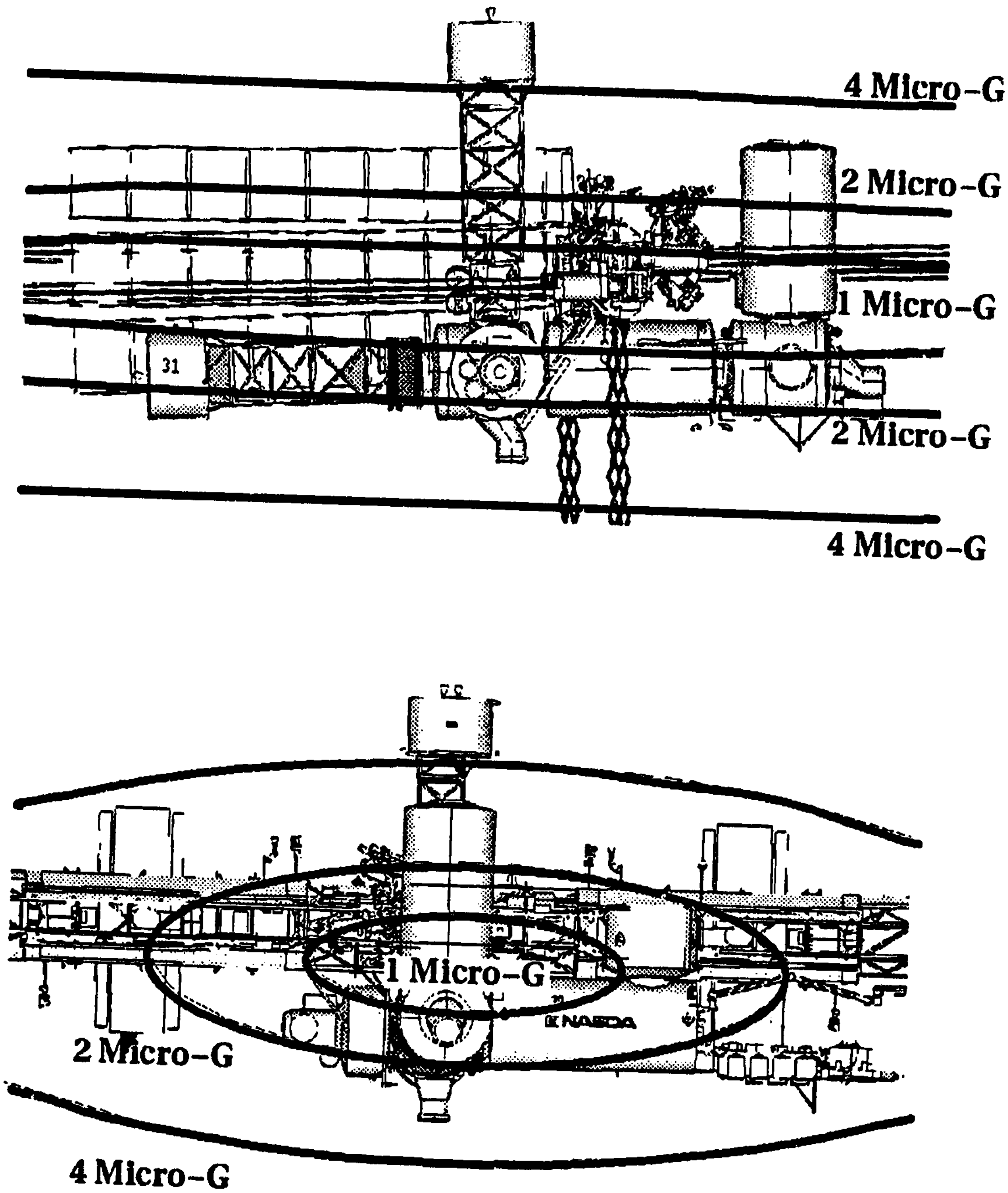


Figure 5.31.4-1 Stage 31 steady-state microgravity environment contours.

Table 5.31.4-2 summarizes the reboost lifetime characteristics of Stage 31 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 9.9 lbs/ft^2. The reboost is performed using the zenith Bus which currently has a reboost efficiency of 84%, while the aft bus has fully expended its propellant load. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.31.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	236	1,458	-231	6,655	275

The control characteristics of Stage 31 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.31.4-2. Table 5.31.4-3 summarizes the control characteristics depicted in the plots.

Table 5.31.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	-1.8 degrees	0.2 degrees	0.4 degrees	± 0.5 degrees	7700 N-m-s
w/STS	-3.3 degrees	44.4 degrees	-1.7 degrees	± 0.7 degrees	6200 N-m-s

The control characteristics of Stage 31 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.31.4-3. Table 5.31.4-3 summarizes the control characteristics depicted in the plots.

5.31.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

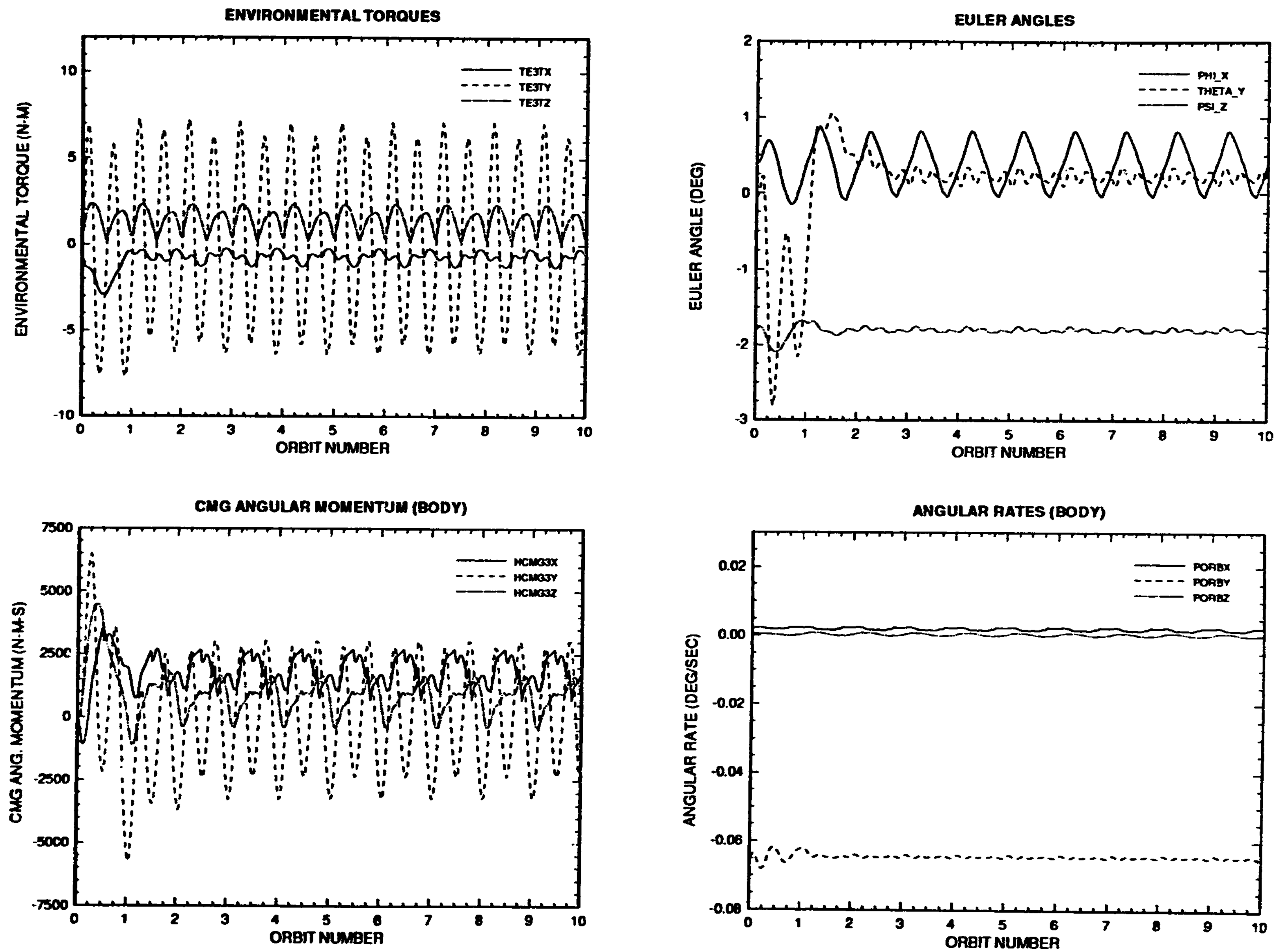


Figure 5.31.4-2 Stage 31 control plots without Shuttle attached.

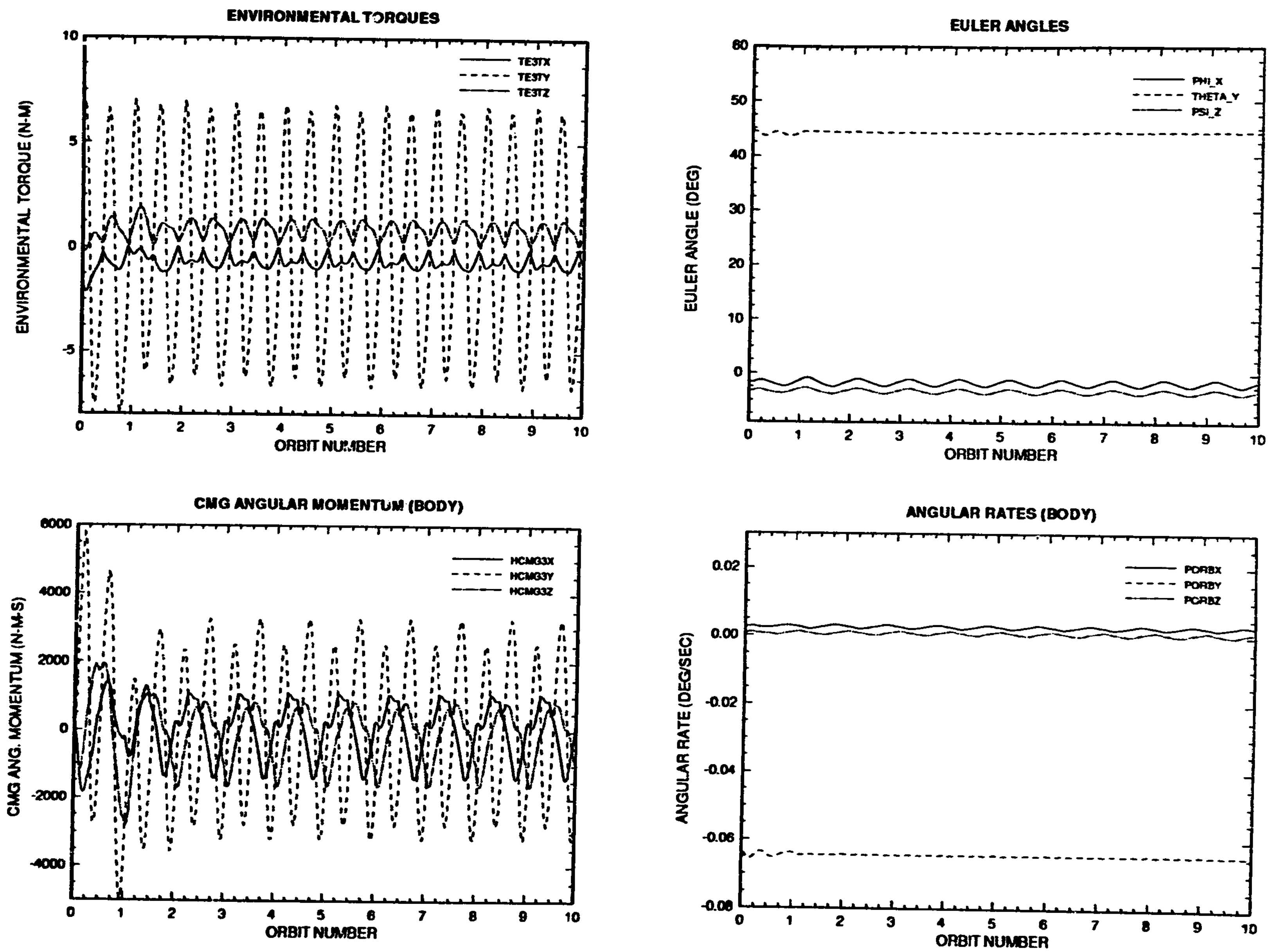


Figure 5.31.4-3 Stage 31 control plots with Shuttle attached.

5.32 Stage 32 Flight Characterization

5.32.1 Stage 32 - Flight 1E Shuttle Flight Manifest

Assembly Flight 1E delivers the European Space Agency's Attached Pressurized Module (APM). Table 5.32.1-1 lists the Shuttle Flight Manifest for Stage 32 - Flight 1E. The total mass of the station hardware to orbit is 26467 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 27908 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 1441 lbs.

5.32.2 Stage 32 Configuration

Figure 5.32.2-1 displays the isometric view of Stage 32 after the Shuttle departs and the scheduled assembly is completed. Figure 5.32.2-2 shows the front, side, top and isometric views of Stage 32 with the Shuttle attached.

5.32.3 Flight 1E Assembly Operations Description

Rendezvous of the Shuttle with the Stage 31 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 1E is a 9 day mission with 1 EVA. The SRMS unberths the ESA COF from the Shuttle payload bay, and hands off the element to the SSRMS, which then attaches the element to the starboard Node 2 CBM. The single EVA involves disconnecting the PMA3-to-Node1 umbilicals to enable PMA3 relocation. The SSRMS relocates PMA3 from the Node 1 nadir port to the Node 2 nadir port (no umbilical connections are made). This is a temporary storage location until the Hab is installed on Node 1.

Following separation, Stage 32 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 31 functionality, plus:

- ESA COF attached to stbd-side of Node 2
- Full activation of all COF systems
- First COF ingress
- COF fully outfitted (10 ISPR's, 3 stowage racks delivered)

Resources Available:	*Power:*	*69,700 W*	
	Thermal:	*TBD*	
	EVA:	*12 crew-hours*	
Resources Required:	*Power:*	*16,691 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		2,600 W	*(ESA)*
		5,600 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*3:00 crew-hours*	

Table 5.32.1-1 Stage 32 - Flight 1E Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
APM		
core	18640	
APM System Rack-1	507	
APM System Rack-2	728	
APM System Rack-3	728	
APM System Rack-4	540	
APM System Rack-5	540	
APM Stowage Rack-1	375	
APM ISPR 1 Rack	882	
APM ISPR 2 Rack	882	
APM ISPR 3 Rack	882	
APM ISPR 4 Rack	882	
APM ISPR 5 Rack	882	
subtotal	**26467**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-1150
Variable Shuttle Consumables		-293
Food & Gear (-55 lbs/day over 6)	165	
5th & 6th N2 tanks (@128 lbs/N2)	128	
	293	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1000
Maintenance Reserve		-800
Total Shuttle Lift Capability		**27908**

Mission Flight Margin		**1441**

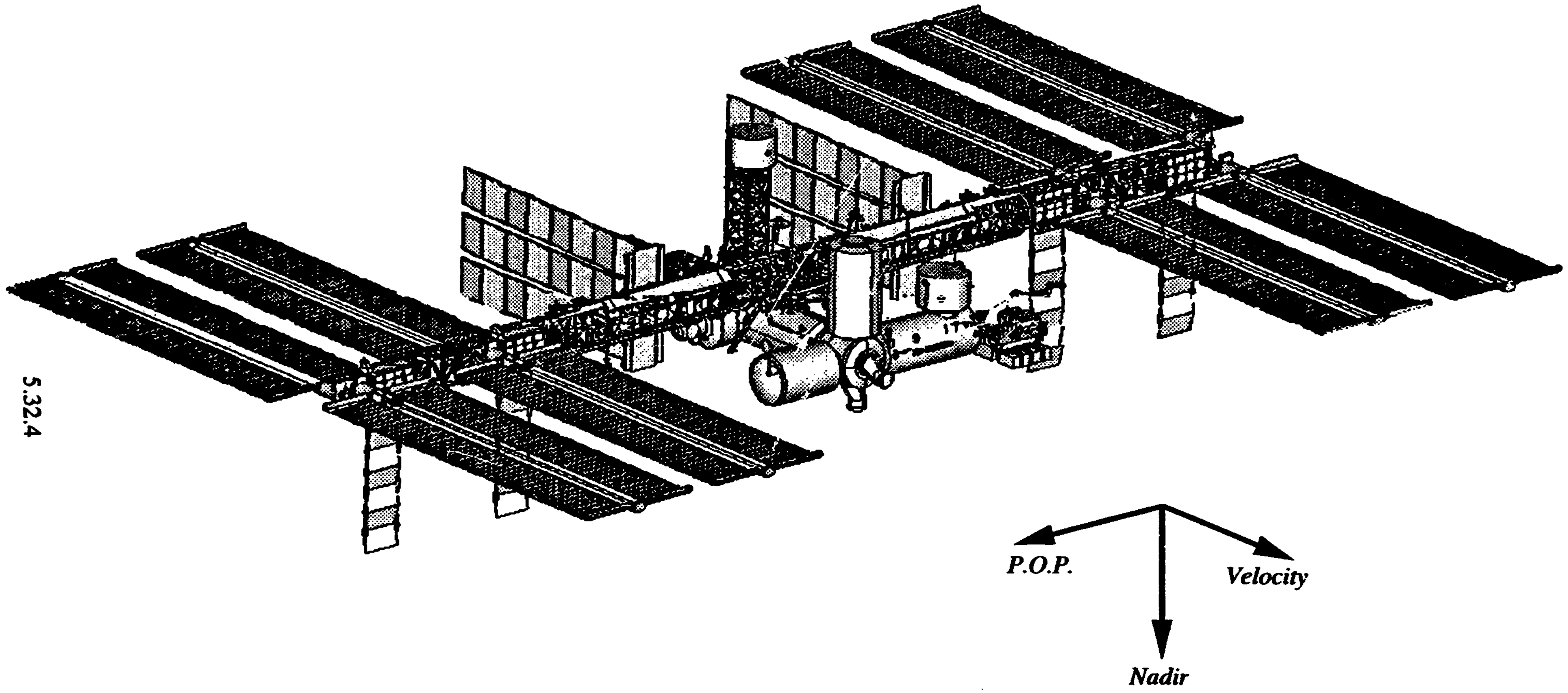


Figure 5.32.2-1 Stage 32 Configuration

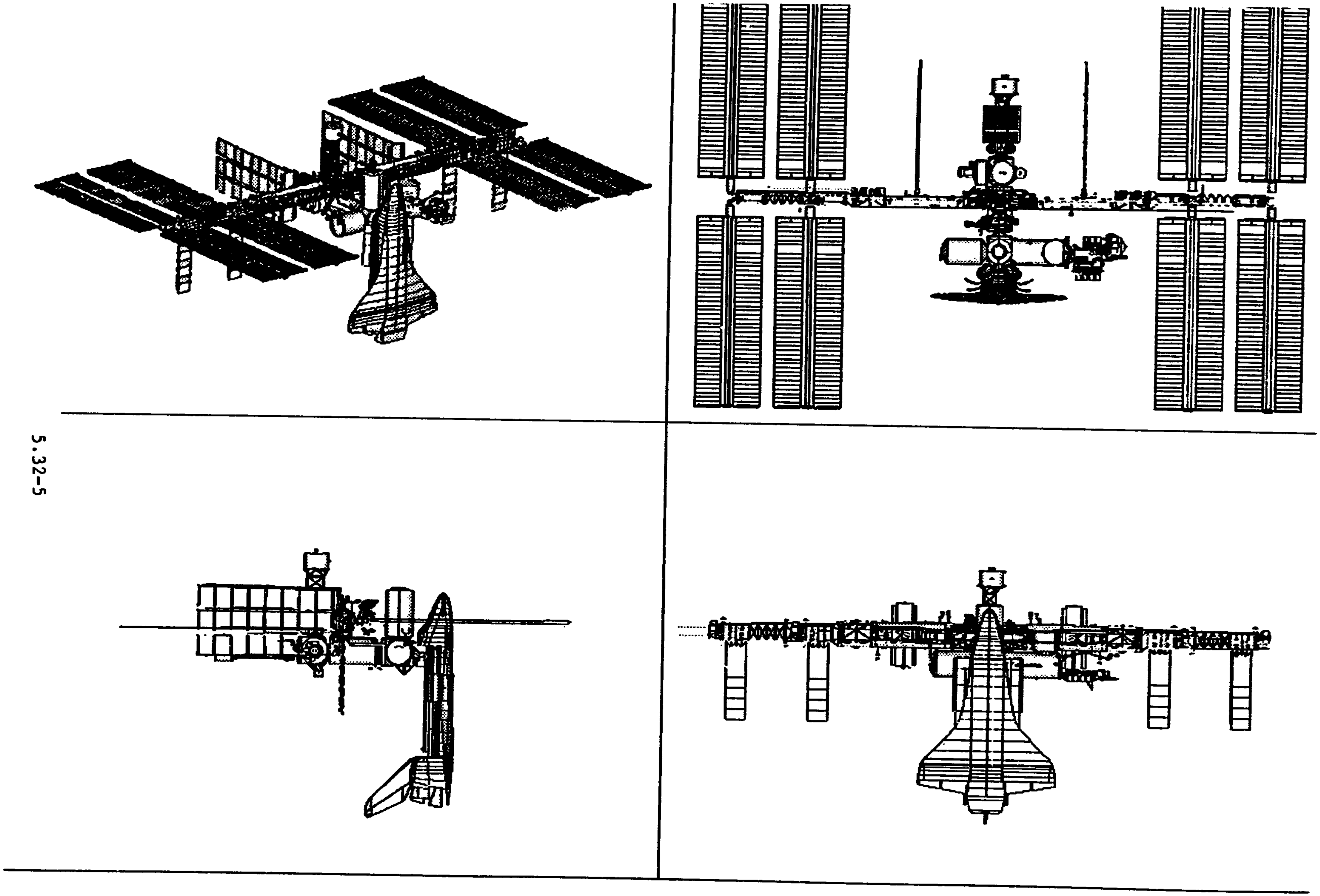


Figure 5.32.2-2 Stage 32 Configuration with Shuttle

5.32 Stage 32, Flight 1E Performance Characteristics

Stage 32, Flight 1E is assembled at a 230 n.mi. altitude in an LVLH flight mode with 4 pairs of double axis articulating PV arrays. The nominal launch date is April, 2003.

Stage 32 in a +2σ atmosphere (solar flux = 118.7, geomagnetic index = 24.5) has a flight attitude of yaw = -1.0, pitch = 5.5, and roll = 0.2. The steady state microgravity environment is depicted in figure 5.32.4-1. Table 5.32.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 6 ISPR racks within the 1 μg environment.

Table 5.32.4-1 Stage 32 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.1
LAS-2	ISPR	1.1
LAS-3	ISPR	1.2
LAS-4	ISPR	1.2
LAS-5	SYS	1.3
LAS-6	SYS	1.3
LAF-1	SYS	1.6
LAF-2	SYS	1.7
LAF-3	SYS	1.7
LAF-4	SYS	1.8
LAF-5	SYS	1.8
LAF-6	SYS	1.9
LAP-1	ISPR	1.0
LAP-2	ISPR	1.1
LAP-3	ISPR	1.1
LAP-4	ISPR	1.2
LAP-5	SYS	1.2
LAP-6	SYS	1.3
LAC-1	ISPR	0.4
LAC-2	ISPR	0.5
LAC-3	ISPR	0.5
LAC-4	ISPR	0.6
LAC-5	ISPR	0.6
LAC-6	SYS	0.7

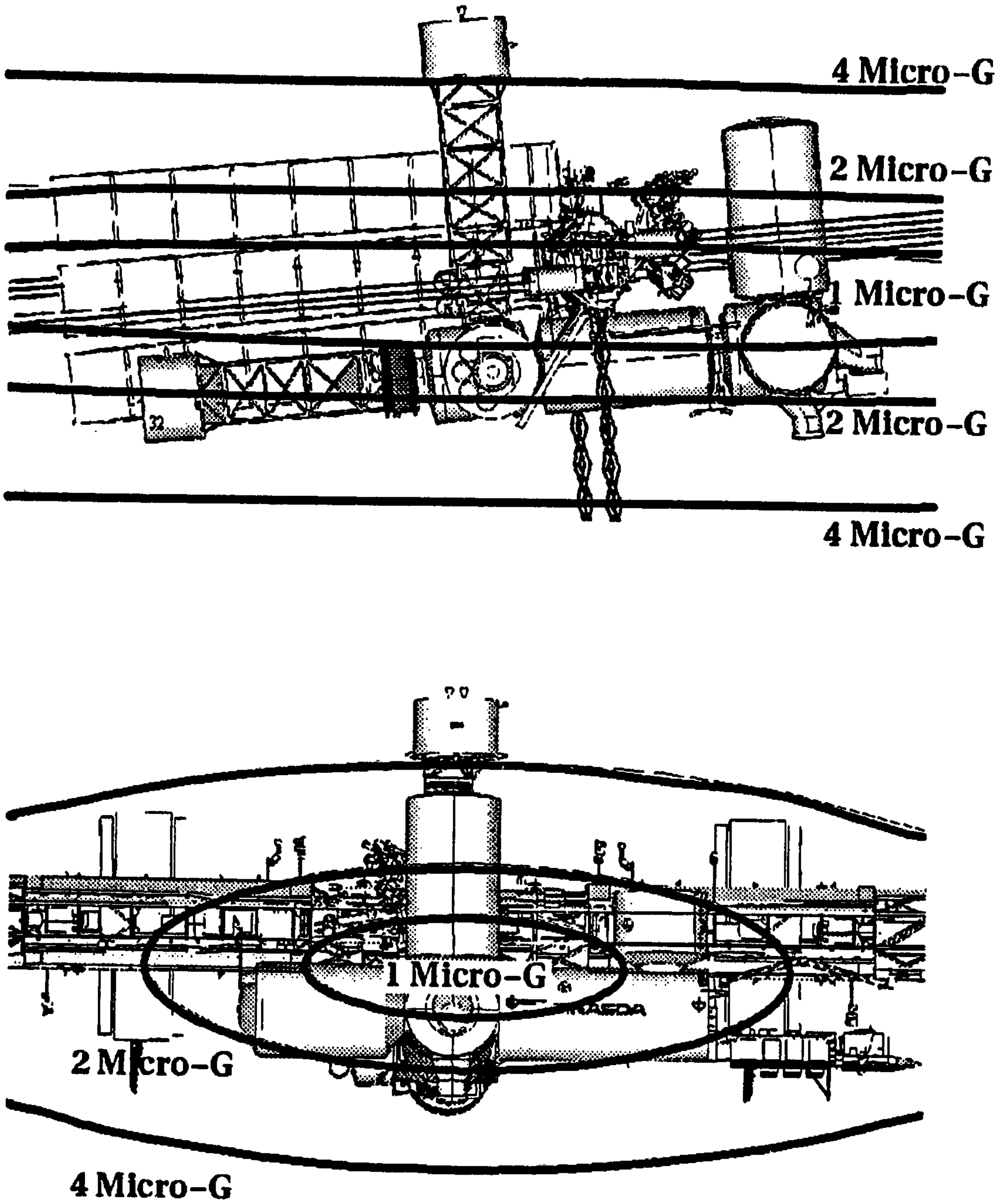


Figure 5.32.4-1 Stage 32 steady-state microgravity environment contours.

Table 5.32.4-2 summarizes the reboost lifetime characteristics of Stage 32 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 10.3 lbs/ft^2. The reboost is performed using the zenith Bus which currently has a reboost efficiency of 81%, while the aft bus has fully expended its propellant load. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.32.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	235	1,434	-231	5,222	309

The control characteristics of Stage 32 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.32.4-2. Table 5.32.4-3 summarizes the control characteristics depicted in the plots.

Table 5.32.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	-1.0 degrees	3.2 degrees	0.2 degrees	± 0.4 degrees	7300 N-m-s
w/STS	-2.3 degrees	45.0 degrees	-1.3 degrees	± 0.8 degrees	6300 N-m-s

The control characteristics of Stage 32 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.32.4-3. Table 5.32.4-3 summarizes the control characteristics depicted in the plots.

5.32.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

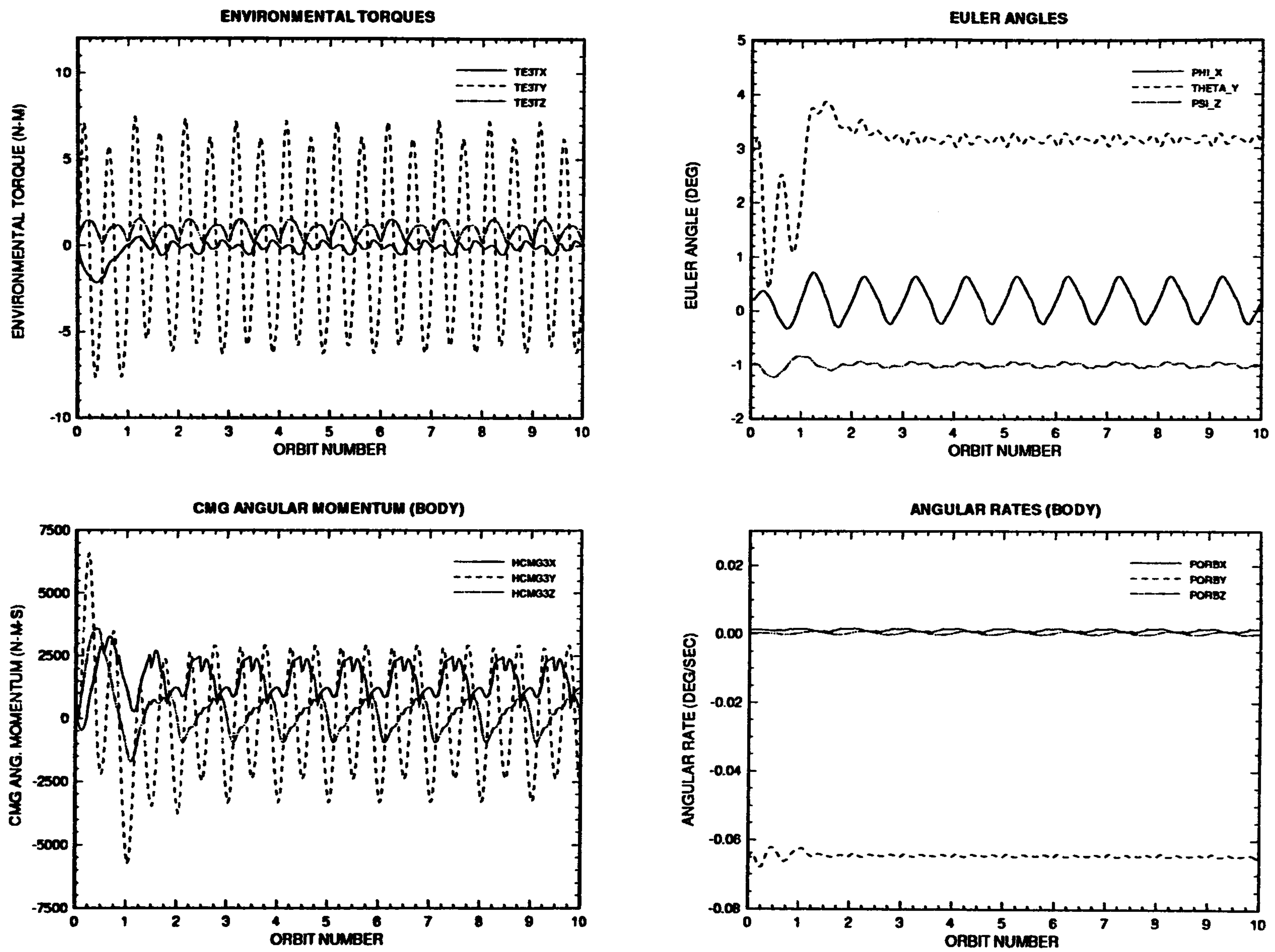


Figure 5.32.4-2: Stage 32 control plots without Shuttle attached.

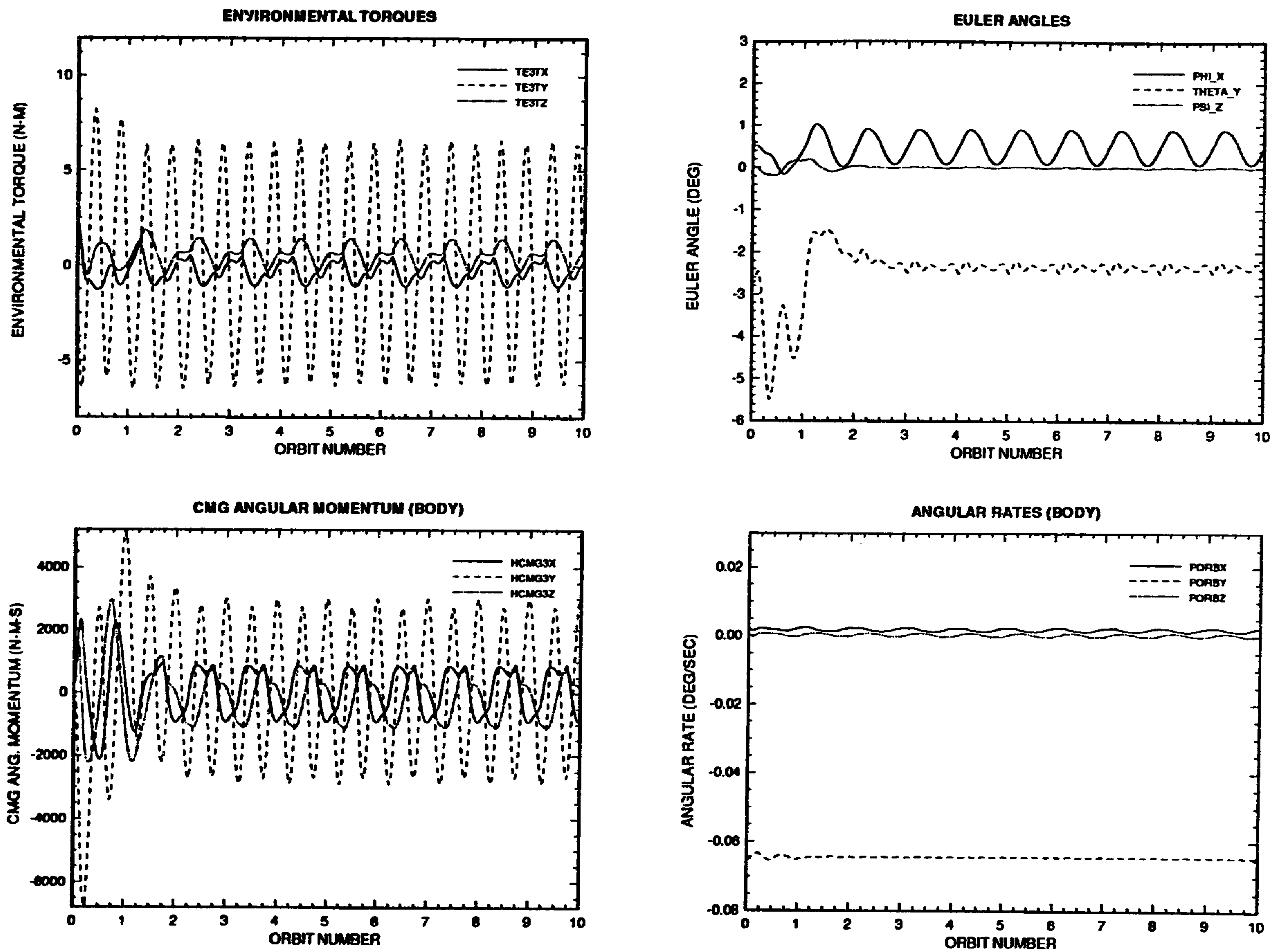


Figure 5.32.4-3 Stage 32 control plots with Shuttle attached.

5.33 Stage 33 Flight Charaterization

5.33.1 Stage 33 - Flight 16A Shuttle Flight Manifest

The Shuttle delivers the U.S. Habitation Module. Table 5.33.1-1 lists the Shuttle Flight Manifest for Stage 33 - Flight 16A. The total mass of the station hardware to orbit is 27502 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 29123 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount gives a mission flight margin of 1621 lbs.

5.33.2 Stage 33 Configuration

Figure 5.33.2-1 displays the isometric view of Stage 33 after the Shuttle departs and the scheduled assembly is completed. Figure 5.33.2-2 shows the front, side, top and isometric views of Stage 33 with the Shuttle attached.

5.33.3 Flight 16A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 32 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 16A is an 8 day mission with 2 EVAs. The SSRMS performs a direct unberthing of the Hab from the Shuttle payload bay and attaches the element to the Node 1 nadir CBM. The two EVAs involve umbilical connections and removal of the thermal cover from the Hab nadir. The SSRMS then relocates PMA3 from the Node 2 nadir port to the Hab nadir port.

Following separation, Stage 33 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 32 functionality, plus:

- Hab attached to Nadir port of Node1
- Delivery and activation of the Hab Module
- Provides additional volume and system redundancy
- Provides additional crew habitability equipment

Resources Available:	*Power:*	*69,700 W*	
	Thermal:	*TBD*	
	EVA:	*24 crew-hours*	
Resources Required:	*Power:*	*18,259 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		2,600 W	*(ESA)*
		5,600 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*17:20 crew-hours*	

Table 5.33.1-1 Stage 33 - Flight 16A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
US Habitation Module Core	22789	
US Hab CA/LT TCS Rack - HAP6	935	
US Hab Avionics1 Rack - HAC6	716	
US Hab Avionics 2 Rack - HAF1	639	
US Hab ARS Rack - HAF6	1333	
US Hab Wardroom Rack 1 - HAP1	595	
US Hab Wardroom Rack 2 - HAP2	395	
subtotal	**27502**	**0**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		0
Variable Shuttle Consumables		238
Food & Gear (-55 lbs/day over 6)	110	
5th N2 tanks (@128 lbs/N2)	128	
	238	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1190
Maintenance Reserve		-600
Total Shuttle Lift Capability		**29123**

Mission Flight Margin		**1621**

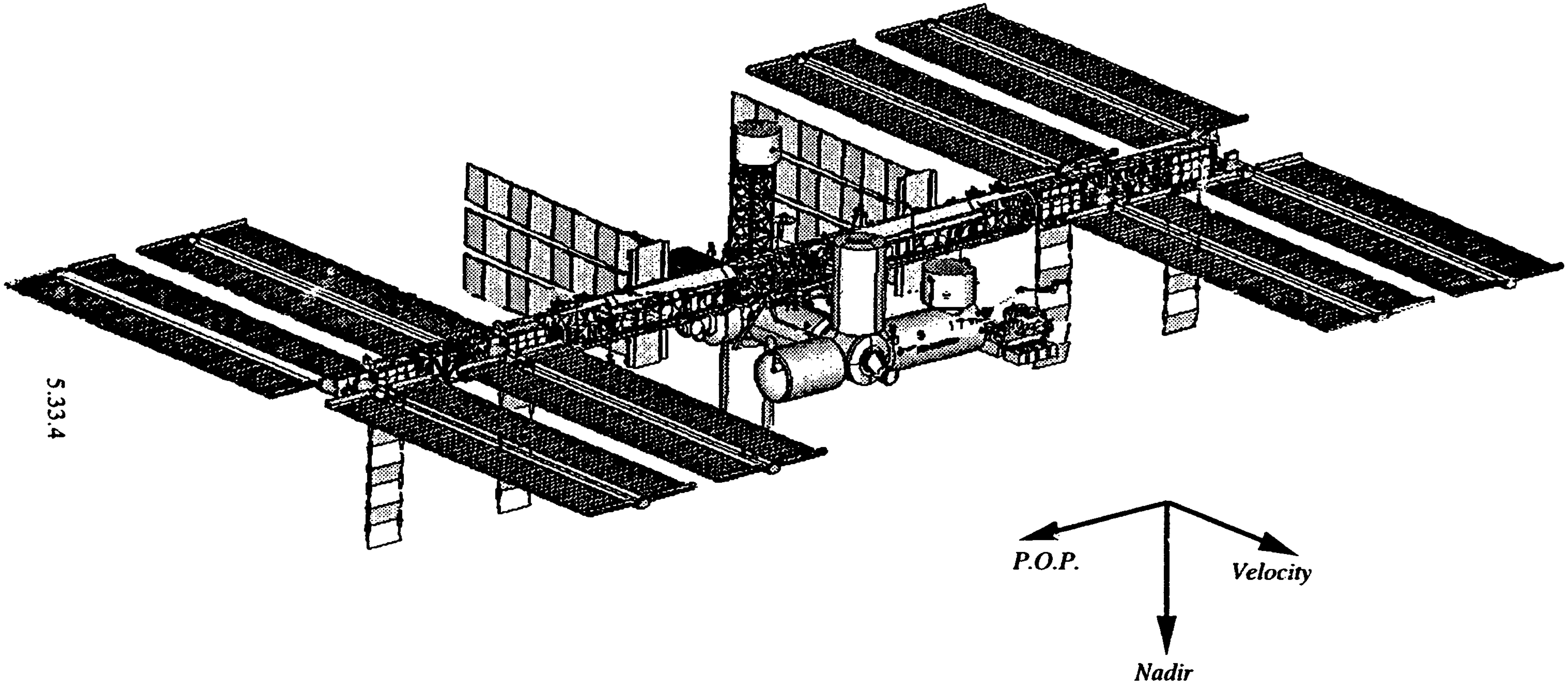


Figure 5.33.2–1 Stage 33 Configuration

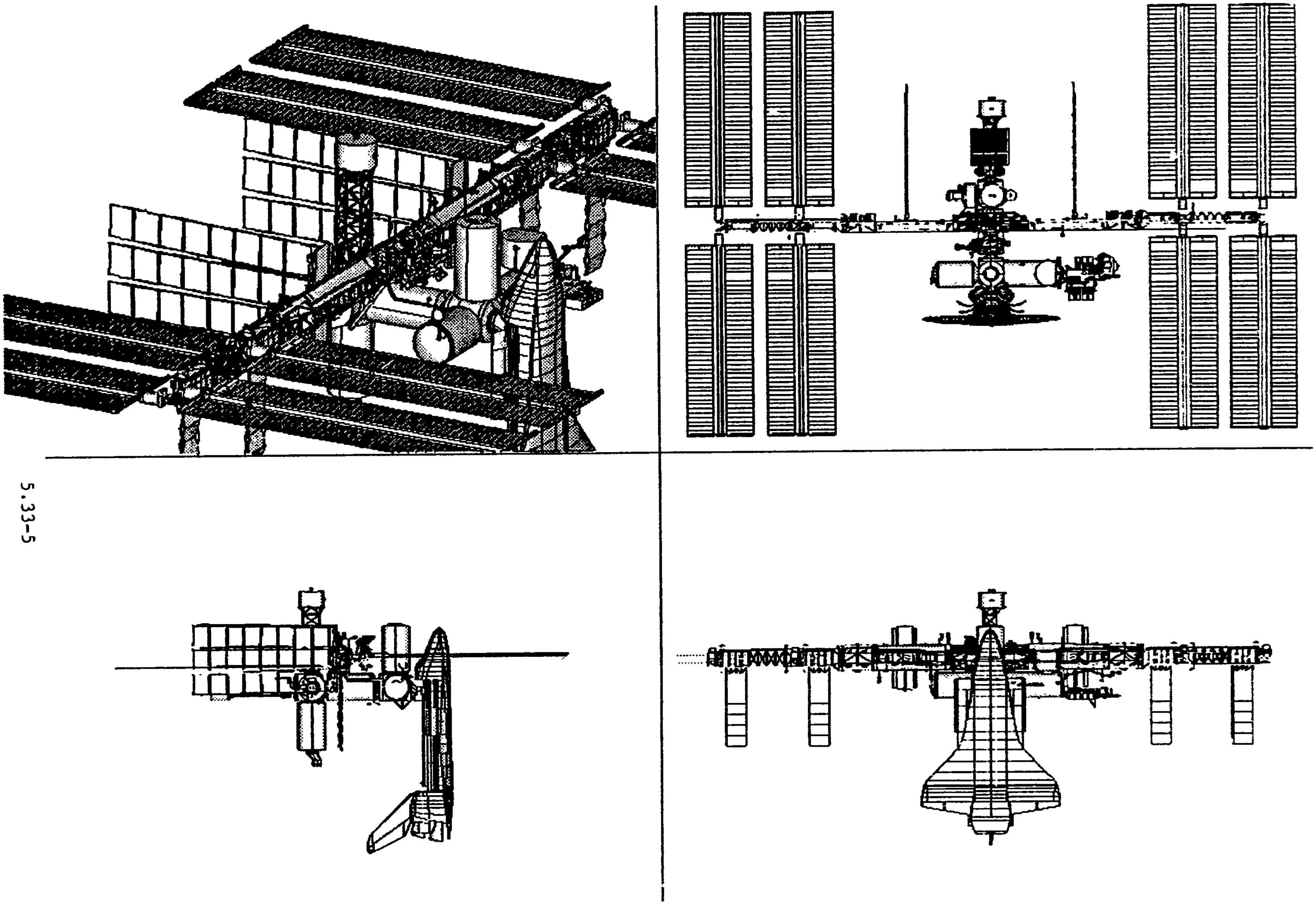


Figure 5.33.2-2 Stage 33 Configuration with Shuttle

5.33 Stage 33, Flight 16A Performance Characteristics

Stage 33, Flight 16A is assembled at a 230 n.mi. altitude in an LVLH flight mode with 4 pairs of double axis articulating PV arrays. The nominal launch date is June, 2003.

Stage 33 in a $+2\sigma$ atmosphere (solar flux = 119.8, geomagnetic index = 22.8) has a flight attitude of yaw = 0.0, pitch = 1.0, and roll = 0.5. The steady state microgravity environment is depicted in figure 5.33.4-1. Table 5.33.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given $+2\sigma$ atmosphere. This configuration contains 5 ISPR racks within the 1 μg environment and all the ISPR racks are less than 1.2 μg.

Table 5.33.4-1 Stage 33 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.1
LAS-2	ISPR	1.2
LAS-3	ISPR	1.2
LAS-4	ISPR	1.2
LAS-5	SYS	1.2
LAS-6	SYS	1.2
LAF-1	SYS	1.8
LAF-2	SYS	1.8
LAF-3	SYS	1.8
LAF-4	SYS	1.8
LAF-5	SYS	1.8
LAF-6	SYS	1.8
LAP-1	ISPR	1.1
LAP-2	ISPR	1.1
LAP-3	ISPR	1.1
LAP-4	ISPR	1.1
LAP-5	SYS	1.1
LAP-6	SYS	1.1
LAC-1	ISPR	0.5
LAC-2	ISPR	0.5
LAC-3	ISPR	0.5
LAC-4	ISPR	0.5
LAC-5	ISPR	0.5
LAC-6	SYS	0.5

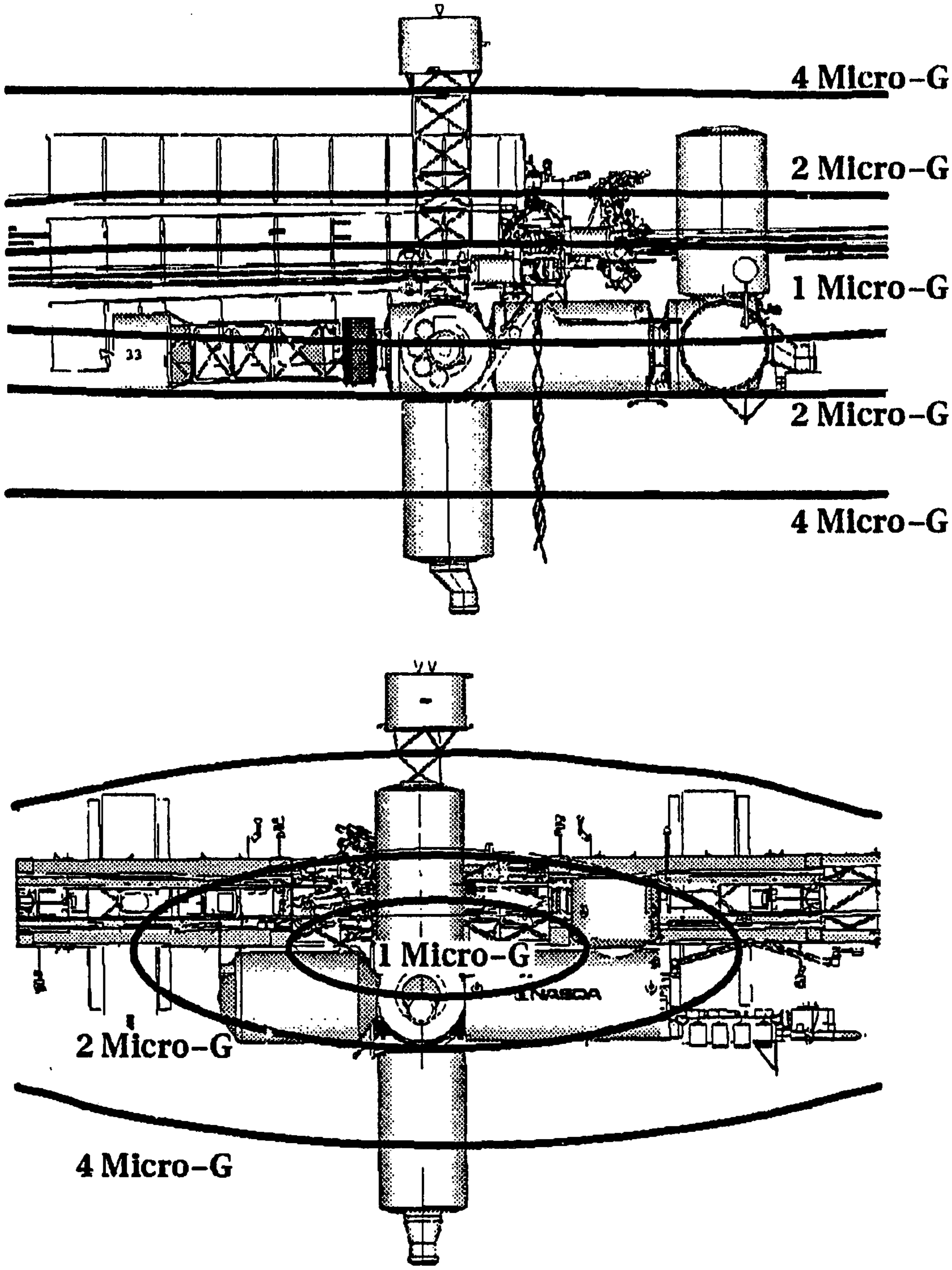


Figure 5.33.4-1 Stage 33 steady-state micrgravity envirinment contours.

Table 5.33.4-2 summarizes the reboost lifetime characteristics of Stage 33 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 10.7 lbs/ft^2. The reboost is performed using the zenith Bus which currently has a reboost efficiency of 83%, while the aft bus has fully expended its propellant load. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.33.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	234	1,186	-231	4,036	346

The control characteristics of Stage 33 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.33.4-2. Table 5.33.4-3 summarizes the control characteristics depicted in the plots.

Table 5.33.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	0.0 degrees	-2.4 degrees	0.5 degrees	± 0.5 degrees	8500 N-m-s
w/STS	-2.3 degrees	43.5 degrees	-1.3 degrees	± 0.7 degrees	7100 N-m-s

The control characteristics of Stage 33 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figures 5.33.4-3. Table 5.33.4-3 summarizes the control characteristics depicted in the plots.

5.33.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

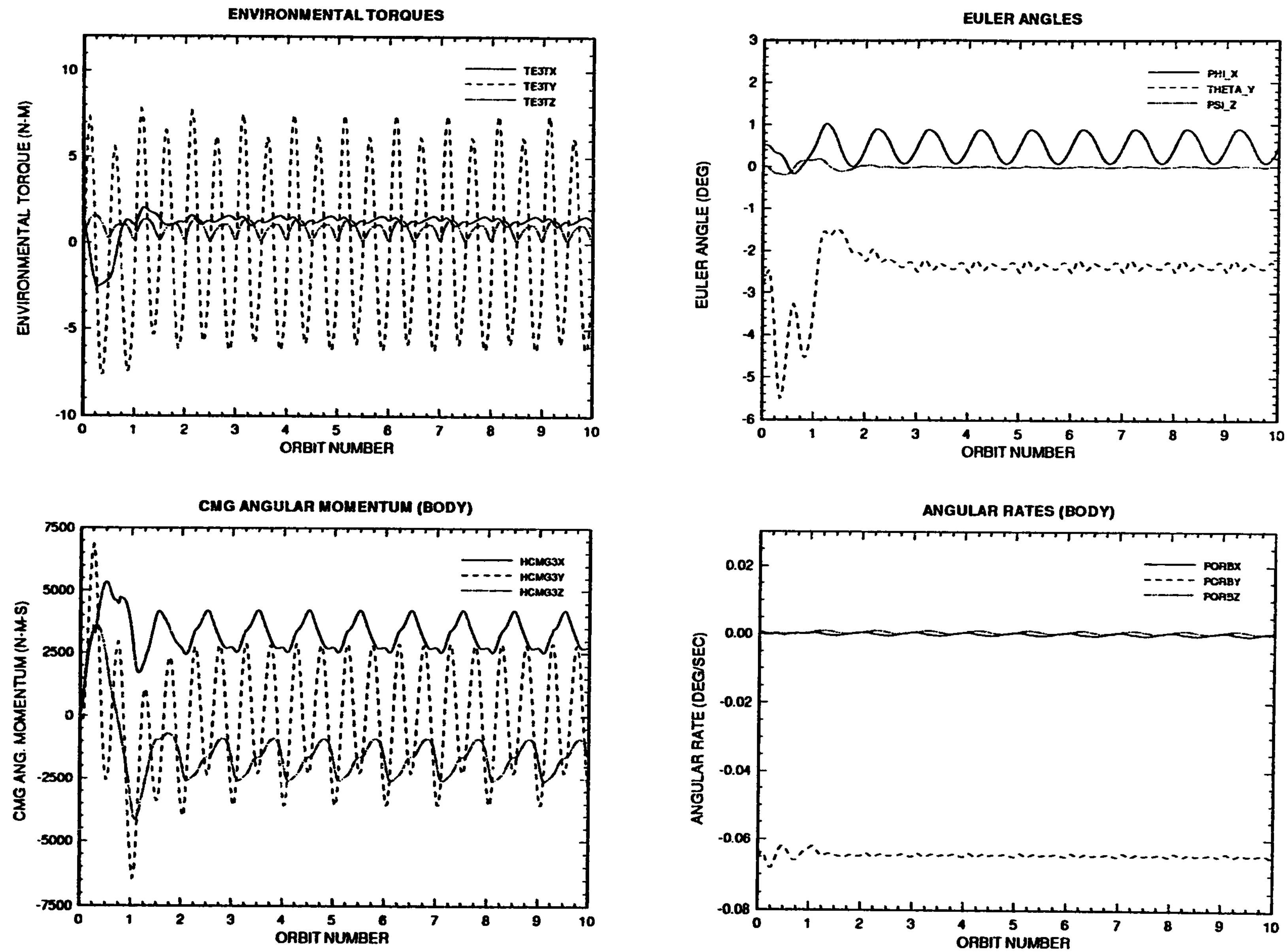


Figure 5.33.4-2 Stage 33 control plots without Shuttle attached.

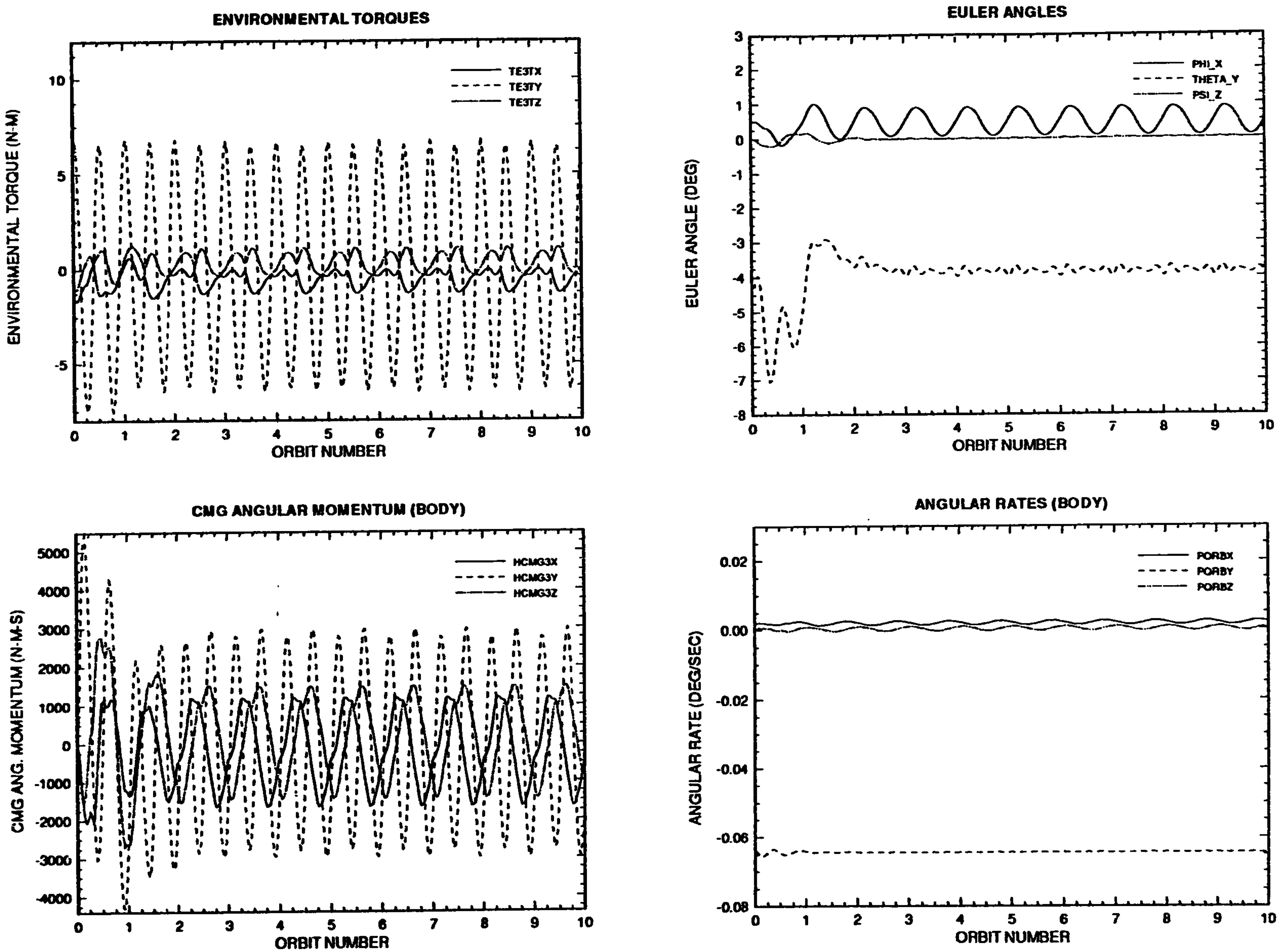


Figure 5.33.4-3 3 control plots with Shuttle attached.

5.34 Stage 34 Flight Characterization

5.34.1 Stage 34, Flight 17A Shuttle Flight Manifest

The Shuttle delivers the MPLM outfitted with U.S. Habitation racks. Table 5.34.1-1 lists the Shuttle Flight Manifest for Stage 34 - Flight 17A. The total mass of the station hardware to orbit is 10913 lbs and FSE mass of 15101 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 27501 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a mission flight margin of 1487 lbs.

5.34.2 Stage 34 Configuration

Figure 5.34.2-1 displays the isometric view of Stage 34 after the Shuttle departs and the scheduled assembly is completed. Figure 5.34.2-2 shows the front, side, top and isometric views of Stage 34 with the Shuttle attached.

5.34.3 Flight 17A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 33 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

The SSRMS unberths the MPLM from the Shuttle payload bay and then berths the element to the Node 2 nadir port for Hab/Lab systems outfitting. The SSRMS directly unberths the ULC from the Shuttle payload bay and installs the element on the MSC. The MSC translates to S6 where PV battery sets (2) are installed using the SPDM. Upon completion of offloading the MPLM, the Lab temporary CHeCS rack is transferred into the MPLM and the SRMS returns the MPLM to the payload bay.

Following separation, Stage 34 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

System Resource/Functionality

Stage 33 functionality, plus:

- 9 racks delivered and activated
- Full PV battery complement on S6

Resources Available:	*Power:*	*76,200 W*	
	Thermal:	*TBD*	
	EVA:	*0 crew-hours*	
Resources Required:	*Power:*	*19,683 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		2,600 W	*(ESA)*
		5,600 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*0 crew-hours*	

Table 5.34.1-1 Stage 34 Flight 17A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
MPLM		10626
US Lab Fuel Cell Water - LAF4	1061	
US Hab Water Processor - HAF3	1430	
US Hab Urine Processor - HAF4	1178	
US Hab Waste Management - HAP5	786	
US Hab Full Body Cleansing - HAP4	580	
US Hab Galley/Oven/Drink - HAS1	1015	
US Hab Crew Health Rack 1 - HAC4	685	
US Hab EHS CHeCS Rack 2 - HAC5	1020	
US Hab CMS CHeCS Rack 3 - HAS4	1290	
ULC-B		2935
DDC-B		1540
2 PV battery sets for S6 PV(on ULC)	1868	
subtotal	**10913**	**15101**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-990
Additional Attach Hardware	990	
	990	
Variable Shuttle Consumables		-110
Food & Gear (-55 lbs/day over 6)	110	
	110	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-2080
Maintenance Reserve		-470
Total Shuttle Lift Capability		**27501**
Mission Flight Margin		**1487**

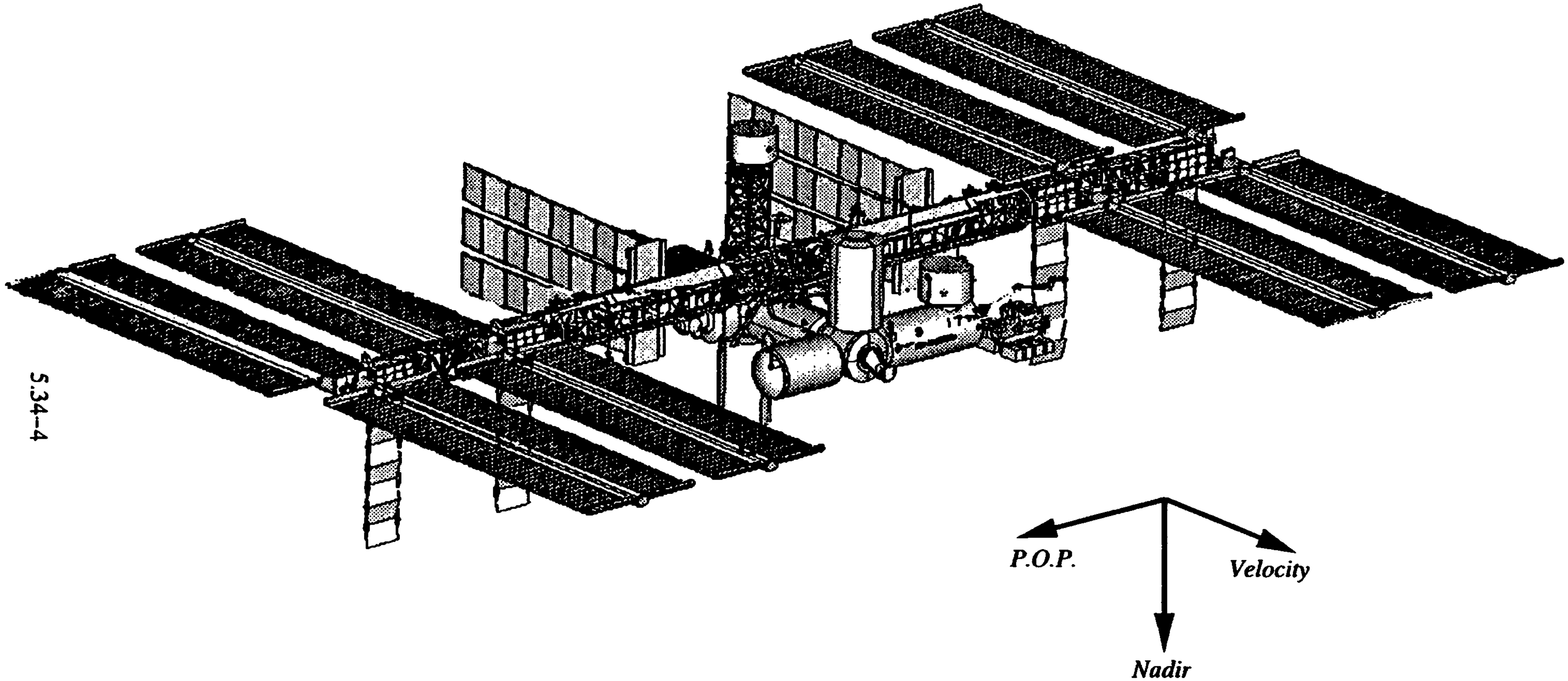


Figure 5.34.2-1 Stage 34 Configuration

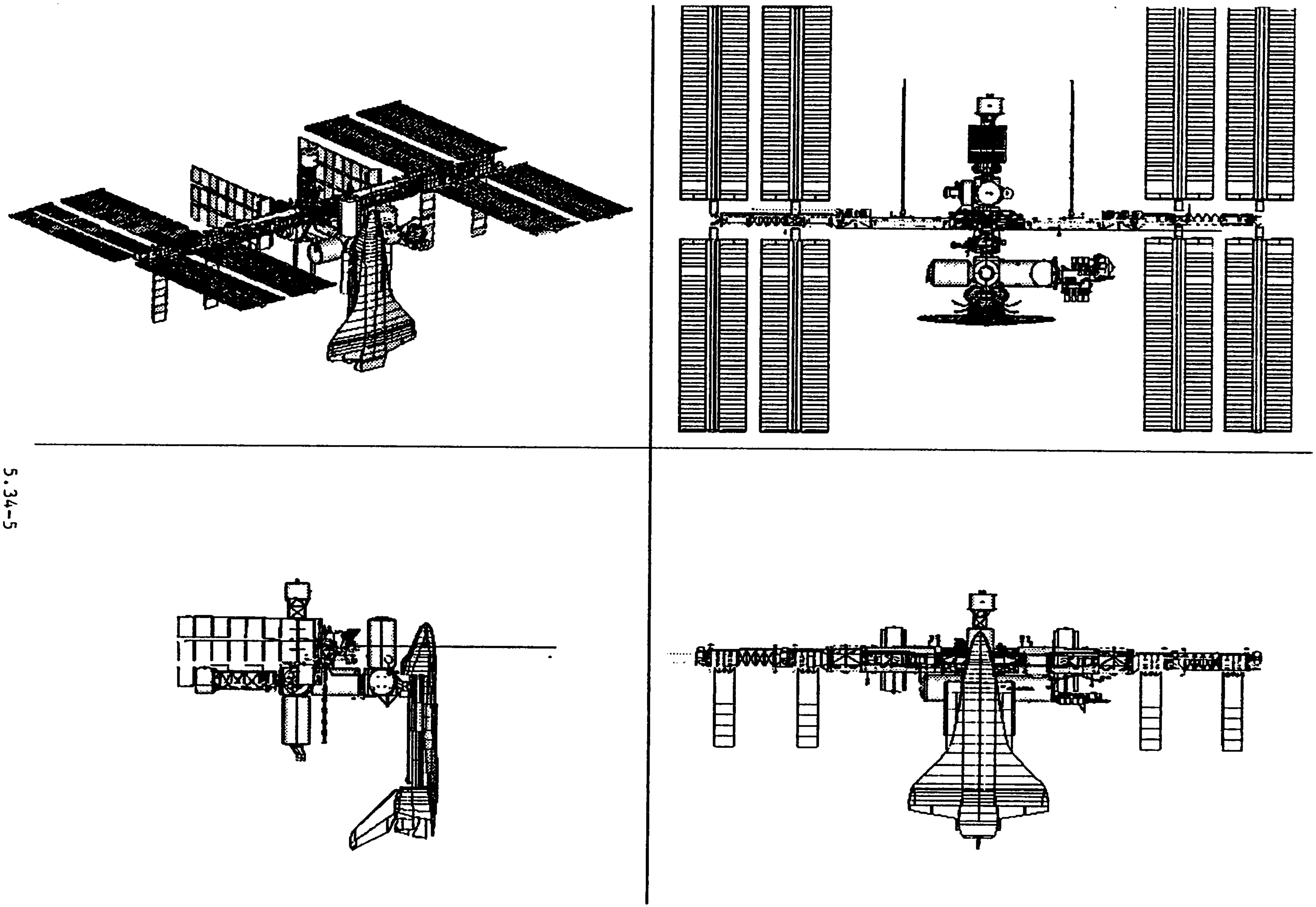


Figure 5.34.2-2 Stage 34 Configuration with Shuttle

5.34.4 Stage 34, Flight 17A Performance Characteristics

Stage 34, Flight 17A is assembled at a 230 n.mi. altitude in an LVLH flight mode with 4 pairs of double axis articulating PV arrays. The nominal launch date is August, 2003.

Stage 34 in a +2σ atmosphere (solar flux = 117.7, geomagnetic index = 21.8) has a flight attitude of yaw = 0.0, pitch = -0.2, and roll = 0.5. The steady state microgravity environment is depicted in figure 5.34.4-1. Table 5.34.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 5 ISPR racks within the 1 μg environment and all the ISPR racks are less than 1.2 μg.

Table 5.34.4-1 Stage 34 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.1
LAS-2	ISPR	1.1
LAS-3	ISPR	1.1
LAS-4	ISPR	1.1
LAS-5	SYS	1.1
LAS-6	SYS	1.1
LAF-1	SYS	1.8
LAF-2	SYS	1.8
LAF-3	SYS	1.8
LAF-4	SYS	1.8
LAF-5	SYS	1.8
LAF-6	SYS	1.8
LAP-1	ISPR	1.1
LAP-2	ISPR	1.1
LAP-3	ISPR	1.1
LAP-4	ISPR	1.1
LAP-5	SYS	1.1
LAP-6	SYS	1.1
LAC-1	ISPR	0.5
LAC-2	ISPR	0.5
LAC-3	ISPR	0.4
LAC-4	ISPR	0.4
LAC-5	ISPR	0.4
LAC-6	SYS	0.4

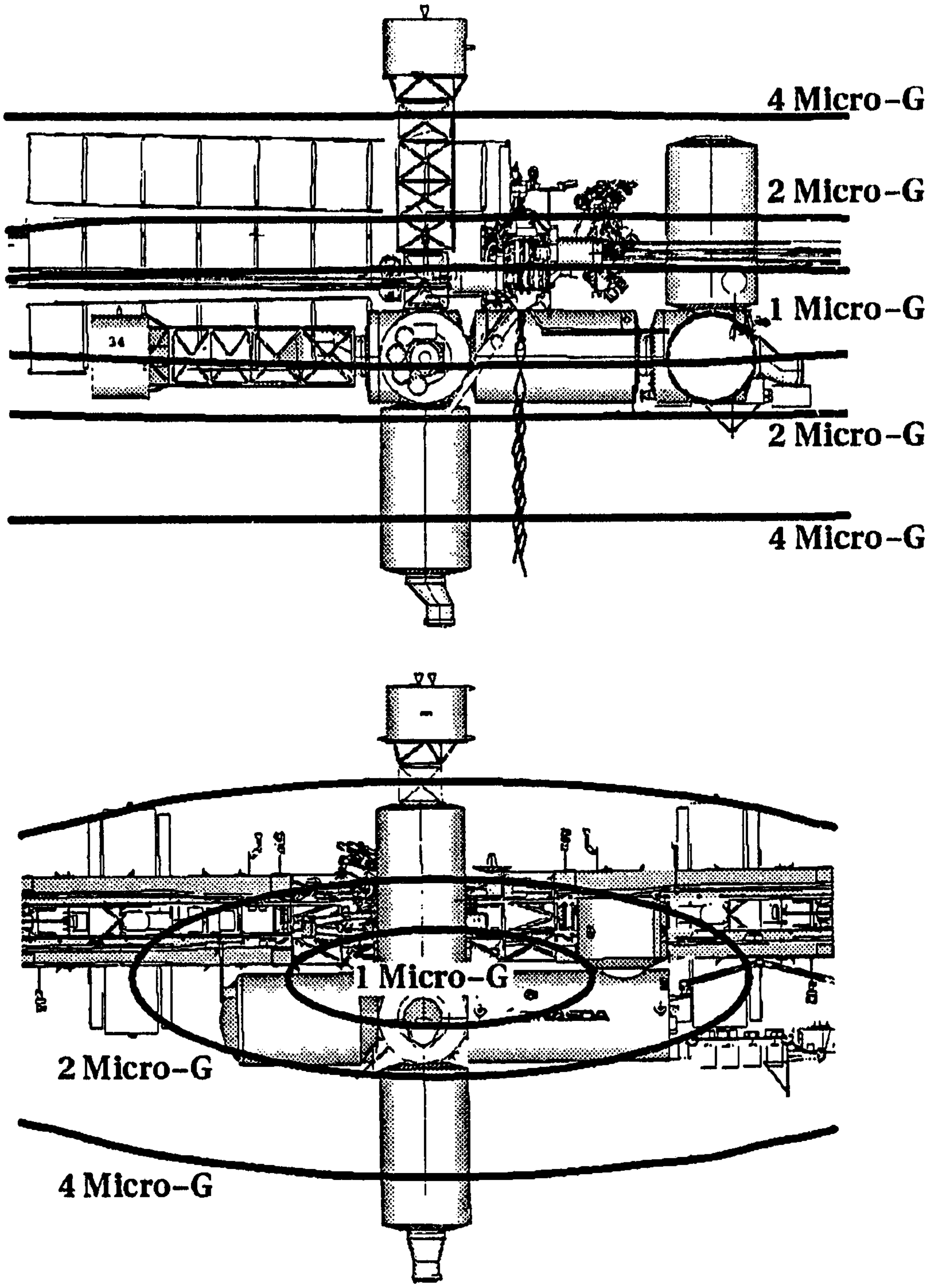


Figure 5.34.4-1 Stage 34 steady-state microgravity environment contours.

Table 5.34.4-2 summarizes the reboost lifetime characteristics of stage 34 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 10.9 lbs/ft^2. The reboost is performed using the zenith Bus which currently has a reboost efficiency of 84%, while the aft bus has fully expended its propellant load. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.34.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	234	1,114	-231	2,692	394

The control characteristics of Stage 34 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.34.4-2. Table 5.34.4-3 summarizes the control characteristics depicted in the plots.

Table 5.34.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	0.0 degrees	-3.8 degrees	0.5 degrees	± 0.5 degrees	8600 N-m-s
w/STS	-2.3 degrees	43.1 degrees	-1.4 degrees	± 0.9 degrees	6000 N-m-s

The control characteristics of Stage 34 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figures 5.34.4-3. Table 5.34.4-3 summarizes the control characteristics depicted in the plots.

5.34.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

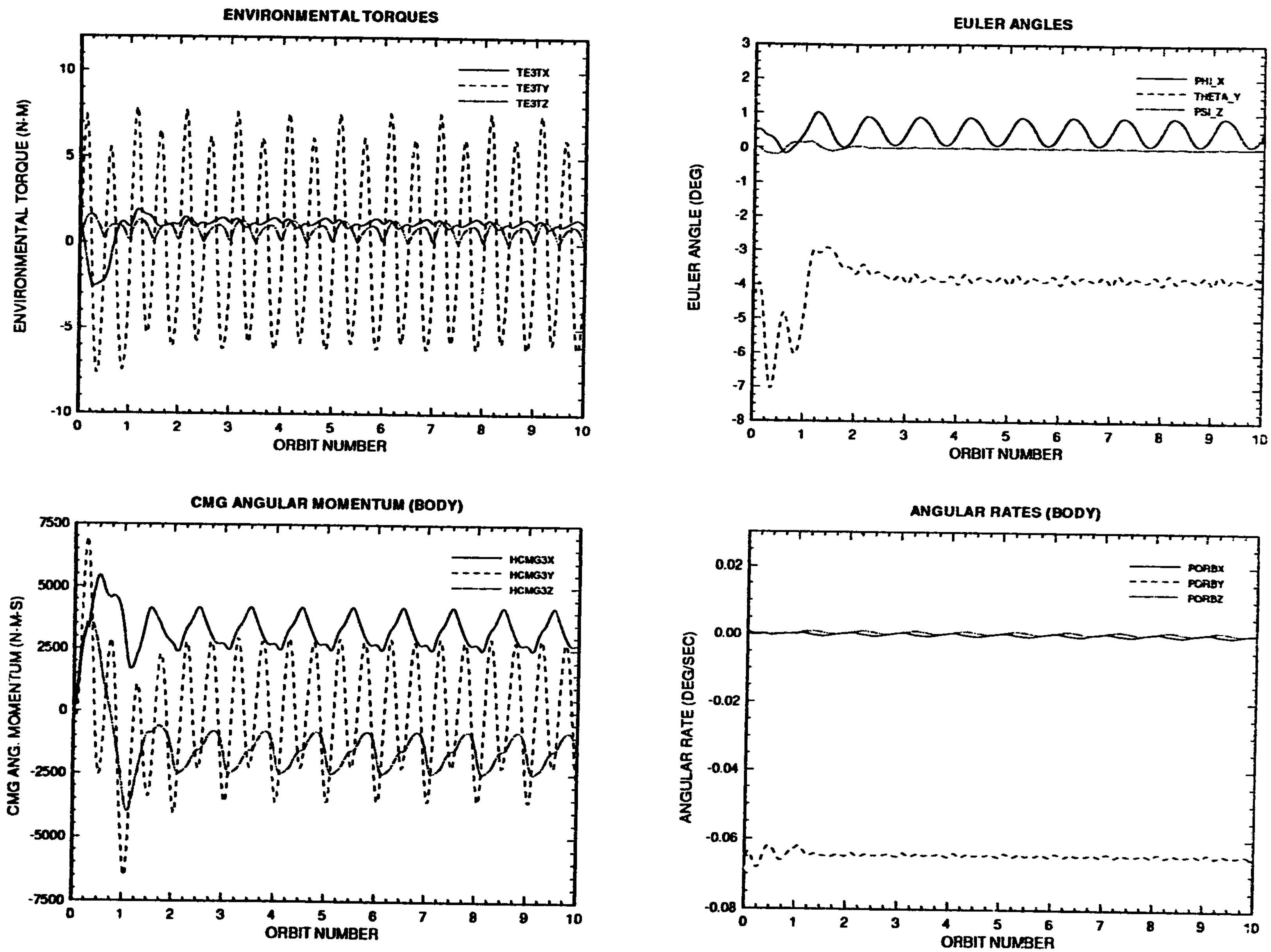


Figure 5.34.4-2: Stage 34 control plots without Shuttle attached.

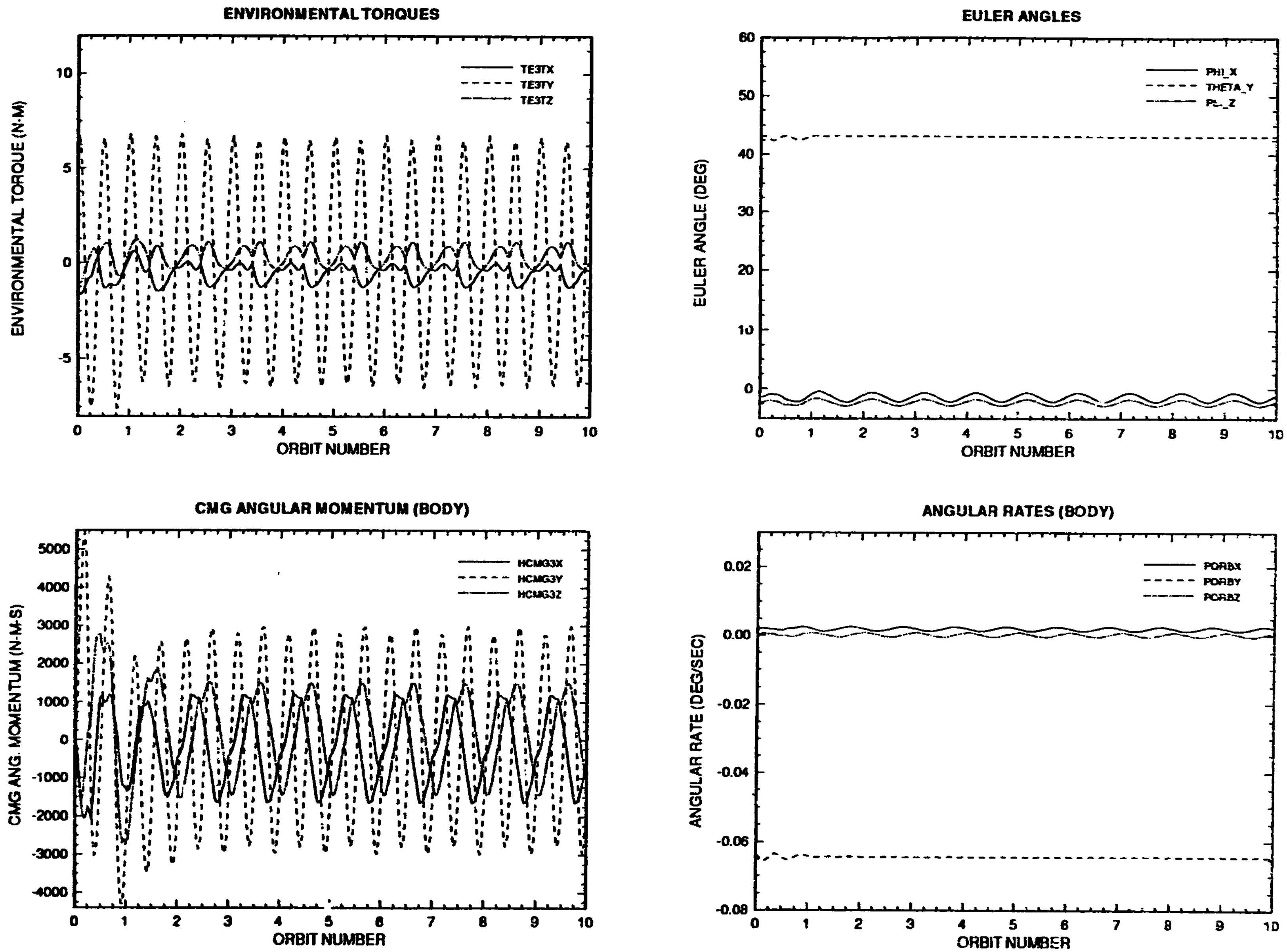


Figure 5.34.4-3 Stage 34 control plots with Shuttle attached.

5.35 Stage 35 Flight Characterization

5.35.1 Stage 35, Flight 18A Shuttle Flight Manifest

The Shuttle delivers the Crew Transfer Vehicle. Table 5.35.1-1 lists the Shuttle Flight Manifest for Stage 35 - Flight 18A. The total mass of the station hardware to orbit is 24255 lbs The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 28931 lbs to 230 n.mi. at an inclination of 51.6°. Subtracting the hardware and FSE subtotals from this amount yields a mission flight margin of 4676 lbs.

5.35.2 Stage 2 Configuration

Figure 5.35.2-1 displays the isometric view of Stage 35 after the Shuttle departs and the scheduled assembly is completed. Figure 5.35.2-2 shows the front, side, top and isometric views of Stage 35 with the Shuttle attached.

5.35.3 Flight 18A Assembly Operations Description

Rendezvous of the Shuttle with the Stage 34 occurs along +V bar at an altitude of 230 n.mi. Station rendezvous attitude is +XVV and +Z Nadir. The Shuttle docks to PMA2 on the Node 2 forward CBM in a tail down orientation.

Flight 18A is an 8 day mission with 0 EVAs planned. The SRMS removes the CTV from the Shuttle payload bay and attaches the vehicle to PMA3 on the Hab nadir port. Following separation, Stage 35 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

<u>System Resource/Functionality</u>

Stage 34 functionality, plus:

- Crew transfer vehicle delivered to orbit

Resources Available:	*Power:*	*76,200 W*	
	Thermal:	*TBD*	
	EVA:	*0 crew-hours*	
Resources Required:	*Power:*	*19,683 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		2,600 W	*(ESA)*
		5,600 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*0 crew-hours*	

Table 5.35.1-1 Stage 35 - Flight 18A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
CTV #1	24255	
subtotal	24255	0

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per Nm)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		0
Variable Shuttle Consumables		-110
Food & Gear (-55 lbs/day over 6)	110	
	110	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1730
Maintenance Reserve		-380
Total Shuttle Lift Capability		28931

Mission Flight Margin		4676

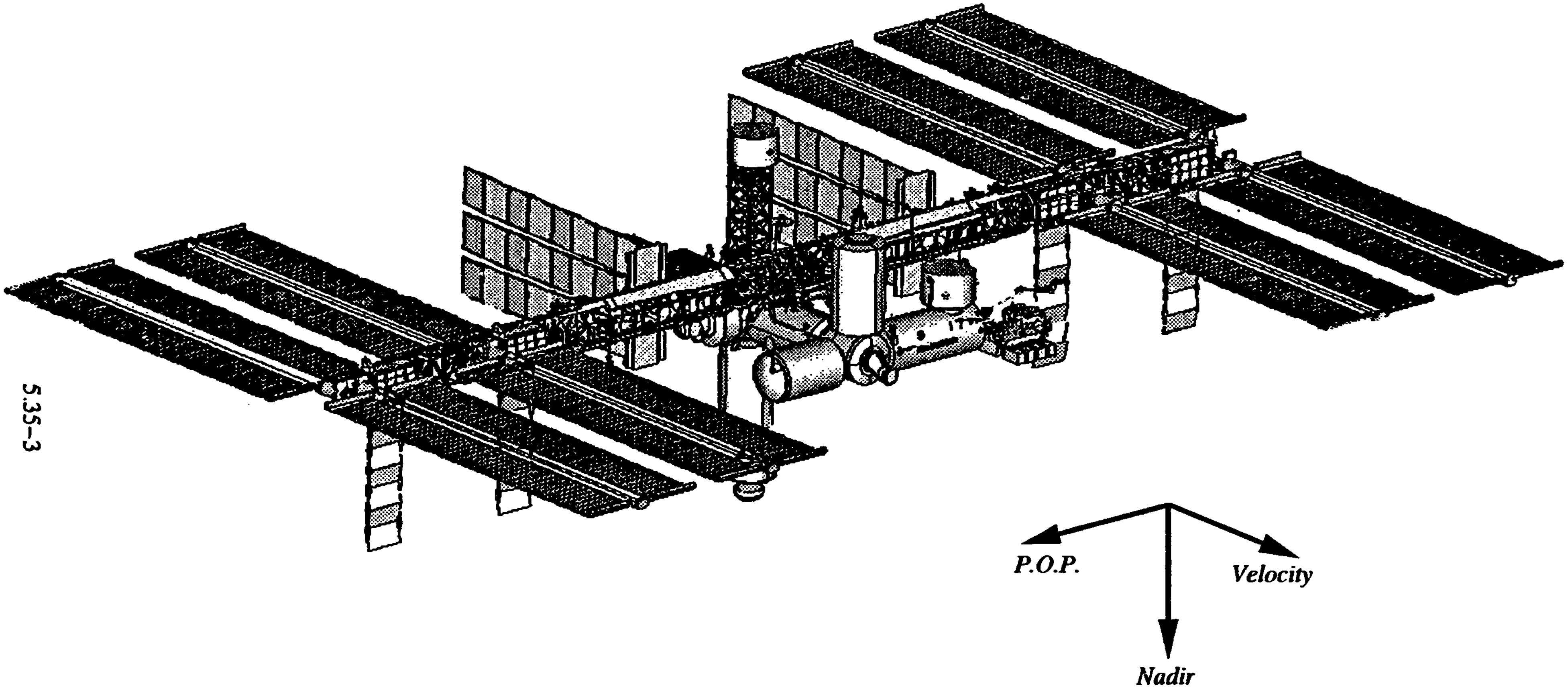


Figure 5.35.2-1 Stage 35 Configuration

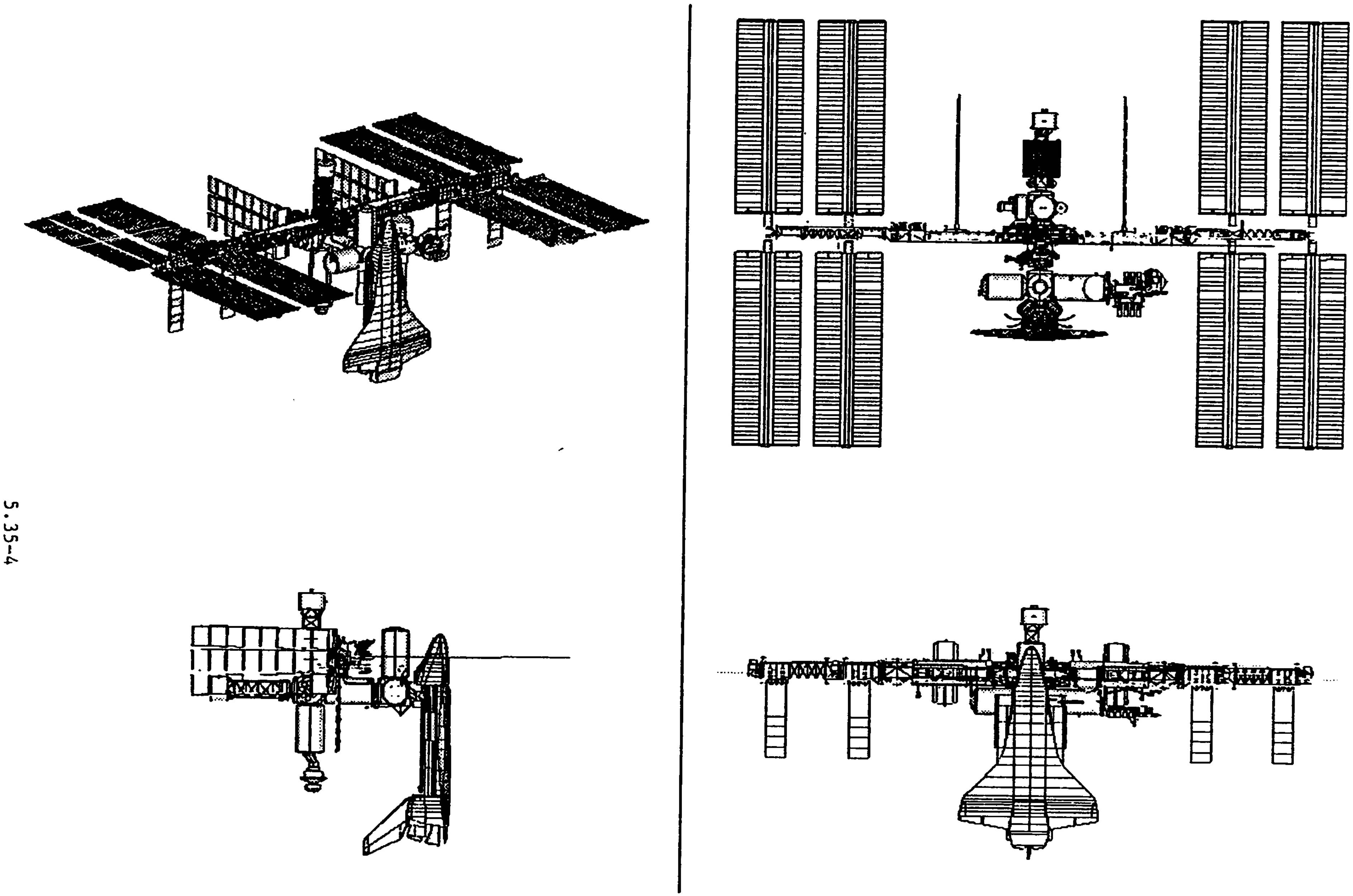


Figure 5.35.2-2 Stage 35 Configuration with Shuttle

5.35.4 Stage 35, Flight 18A Performance Characteristics

Stage 35, Flight 18A is assembled at a 230 n.mi. altitude in an LVLH flight mode with 4 pairs of double axis articulating PV arrays. The nominal launch date is October, 2003.

Stage 35 in a +2σ atmosphere (solar flux = 114.6, geomagnetic index = 21.1) has a flight attitude of yaw =-1.0, pitch = -7.0, and roll = 0.5. The steady state microgravity environment is depicted in figure 5.35.4-1. Table 5.35.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given +2σ atmosphere. This configuration contains 11 ISPR racks within the 1 μg environment.

Table 5.35.4-1 Stage 35 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.1
LAS-2	ISPR	1.0
LAS-3	ISPR	1.0
LAS-4	ISPR	0.9
LAS-5	SYS	0.9
LAS-6	SYS	0.8
LAF-1	SYS	1.7
LAF-2	SYS	1.7
LAF-3	SYS	1.6
LAF-4	SYS	1.5
LAF-5	SYS	1.5
LAF-6	SYS	1.4
LAP-1	ISPR	1.1
LAP-2	ISPR	1.0
LAP-3	ISPR	0.9
LAP-4	ISPR	0.9
LAP-5	SYS	0.8
LAP-6	SYS	0.7
LAC-1	ISPR	0.4
LAC-2	ISPR	0.4
LAC-3	ISPR	0.3
LAC-4	ISPR	0.3
LAC-5	ISPR	0.2
LAC-6	SYS	0.2

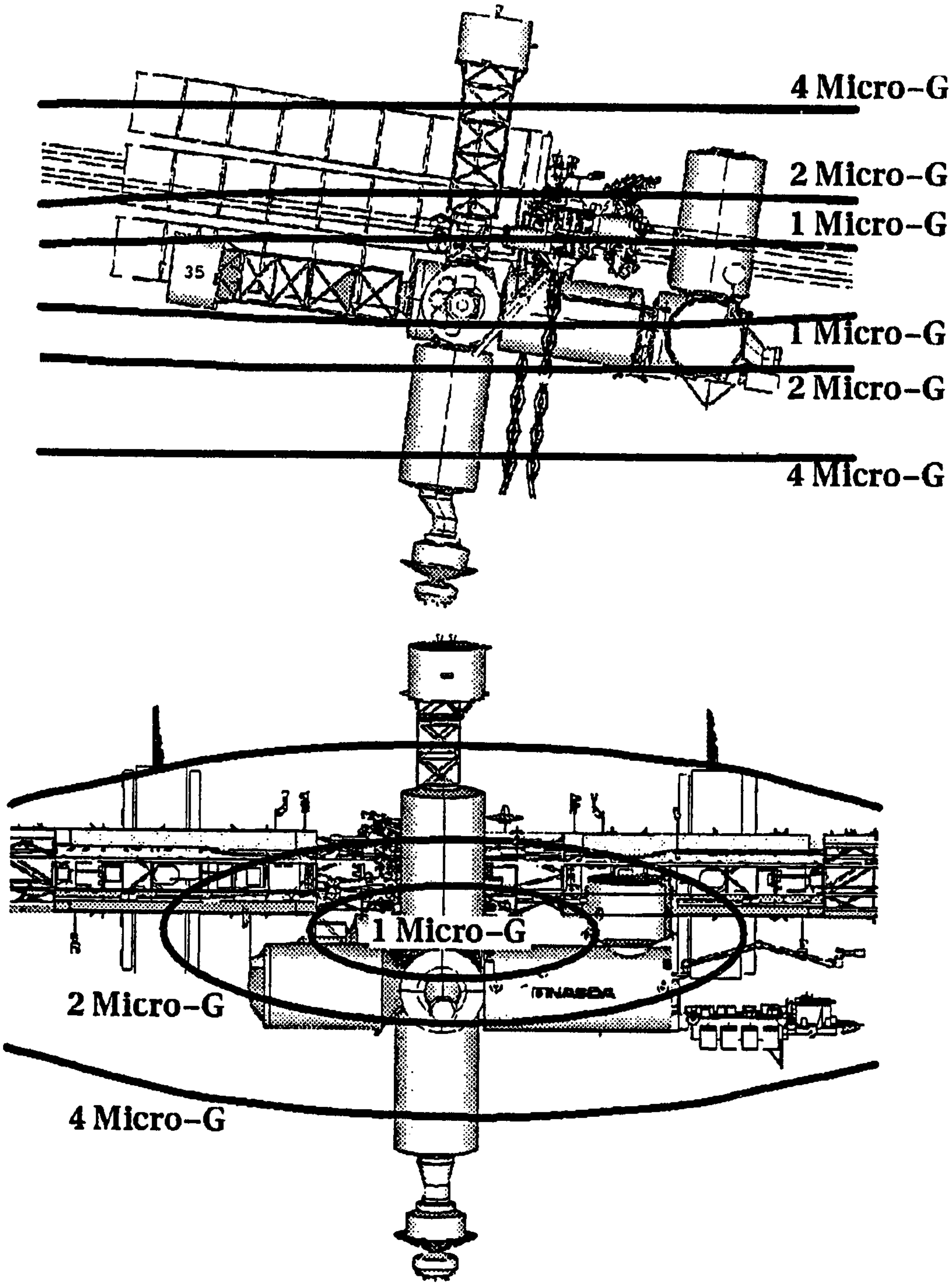


Figure 5.35.4-1 Stage 35 steady-state microgravity environment contours.

Table 5.35.4-2 summarizes the reboost lifetime characteristics of Stage 35 assuming $+2\sigma$ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 11.1 lbs/ft^2. The reboost is performed using the zenith Bus which currently has a reboost efficiency of 86%, while the aft bus has fully expended its propellant load. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.35.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	236	1,626	-231	1,066	420

The control characteristics of Stage 35 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.35.4-2. Table 5.35.4-3 summarizes the control characteristics depicted in the plots.

Table 5.35.4-3 Control Characteristics Summary

	Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
no STS	-1.0 degrees	-13.9 degrees	0.5 degrees	± 0.5 degrees	8300 N-m-s
w/STS	-2.5 degrees	43.6 degrees	-1.5 degrees	± 0.6 degrees	6600 N-m-s

The control characteristics of Stage 35 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.35.4-3. Table 5.35.4-3 summarizes the control characteristics depicted in the plots.

5.35.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

The addition of the CTV eliminates the secondary Shuttle port. In case of a primary port failure, the CTV would have to be relocated to the bottom of node 2 so that the orbiter could dock to the bottom of the habitation module. Another approach would be to place the centrifuge module on the zenith side of node one with the Z1 truss/Bus combination on the top of the centrifuge (this would require a CBM on the top of the centrifuge module). The CTV would be placed on the top of node 2 which would leave the habitation module PMA free to be the secondary Shuttle port.

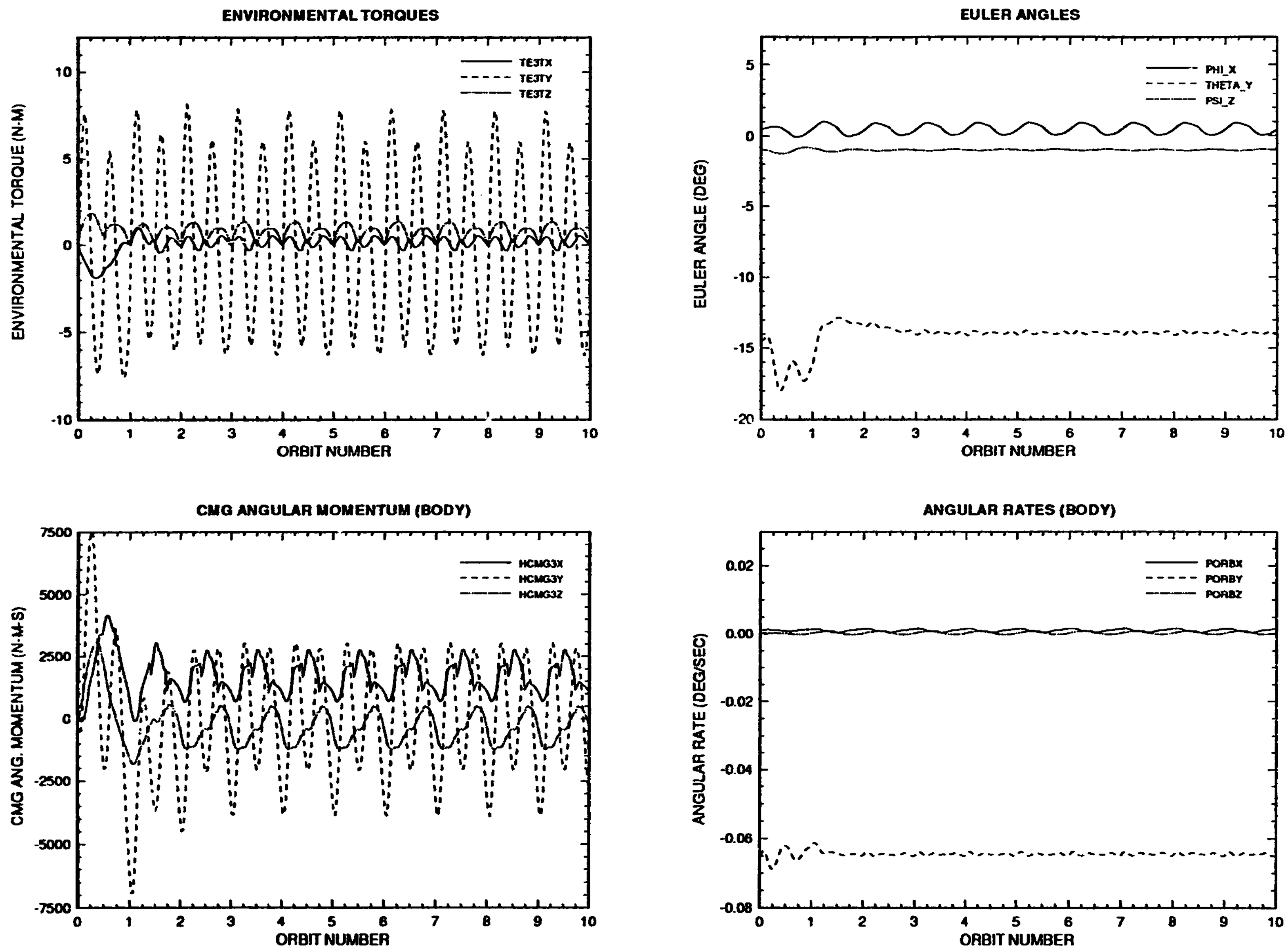


Figure 5.35.4-2: Stage 35 control plots without Shuttle attached.

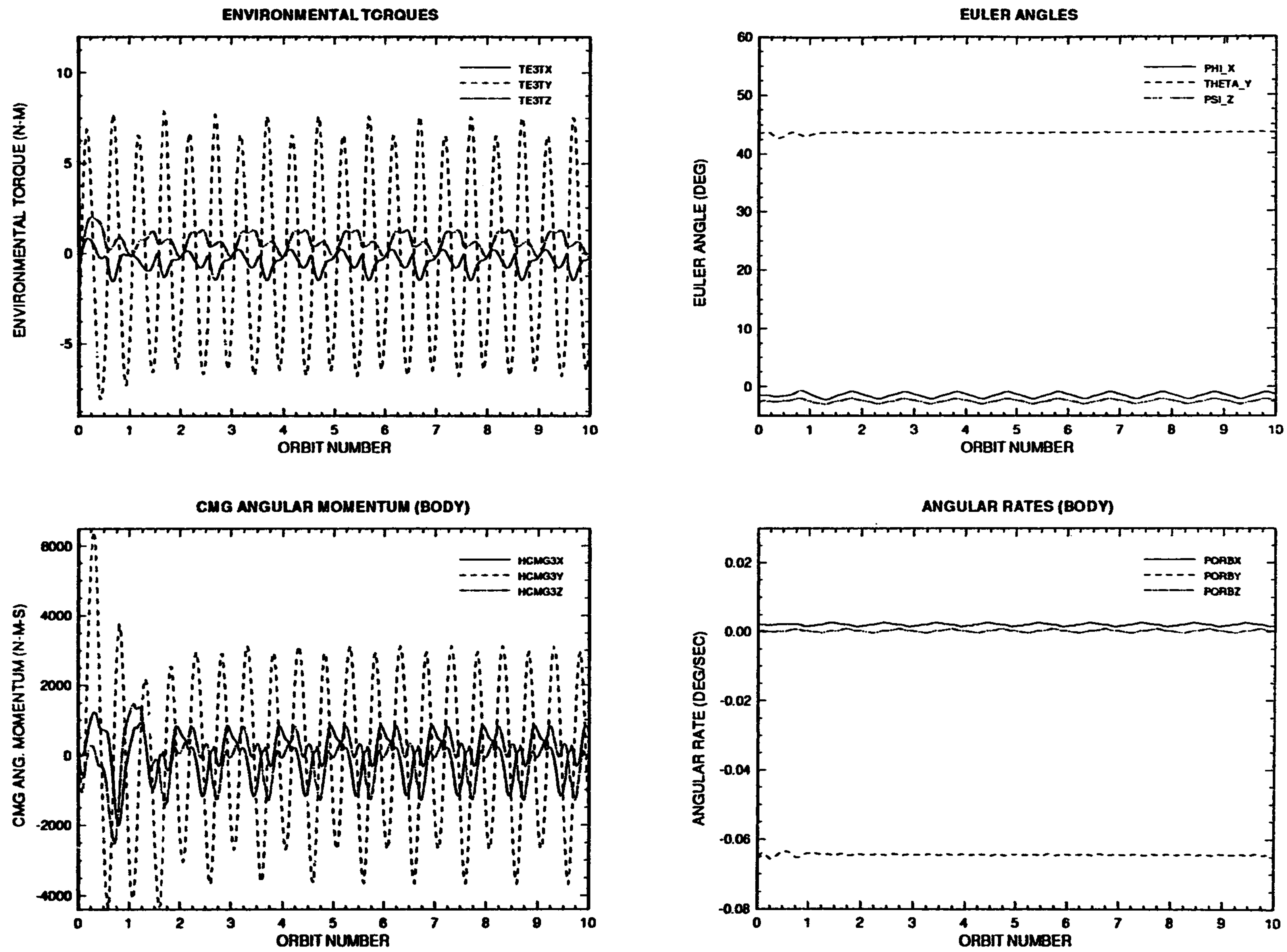


Figure 5.35.4-3 Stage 35 control plots with Shuttle attached.

5.36 Stage 36 Flight Characterization

5.36.1 Stage 36 - Flight 19A Shuttle Flight Manifest

Table 5.36.1-1 lists the Shuttle Flight Manifest for Stage 36 Flight 19A. The total mass of the station hardware to orbit is 14402 lbs, and the FSE total mass is 10705 lbs. The second section of the table shows the Shuttle Performance and hardware/consumables required for the mission resulting in the net Shuttle Lift Capability of 26822 lbs. Subtracting the hardware and FSE subtotals from this amount gives the mission flight margin of 1715 lbs.

5.36.2 Stage 36 Configuration

Figure 5.36.2-1 displays the isometric view of Stage 36 after the Shuttle departs and the scheduled assembly is completed. Figure 5.36.2-2 shows the front, side, top and isometric views of Stage 36 with the Shuttle attached.

5.36.3 Flight 19A Assembly Operations Description

Assembly Flight 19A launches the last of the outfitting flights, and the last in the ISSA Tier 2 assembly sequence. The cargo consists of a Mini-Pressurized Logistics Module (MPLM) with 14 racks manifested. The following racks will be installed in the Hab: Refrigerator/Freezer/Trash Compactor racks, Refrigerator/Freezer rack, Freezer rack, Wardroom/Galley Stowage rack, and the stowage racks. A Node 1 stowage rack will be installed in Node 1. A U.S. Stowage rack will be installed in the JEM. Two U.S. Stowage racks will be installed in the APM. In addition, the Fluid Service System upgrade will be installed in the U.S. Lab. The MPLM is active while in the payload bay so that power and cooling may be provided to the refrigerator/freezers that are in the MPLM.

The Shuttle will rendezvous with the Station along the V-bar at an altitude of 230 n.mi, and then dock to PMA2 which is located on the forward end of Node 2.

On the following day, the crew ingresses the Station and removes the MPLM from the payload bay using the SSRMS and attaches it to the Node 2 nadir port. Utilities to the MPLM are connected and the MPLM is activated. The atmosphere inside the MPLM is verified and then the MPLM is ingressed.

The next day involves the crew transfe-ring and installing the 14 racks from the MPLM to the Station. Once installed, the racks are activated by the ground.

Prior to departure, the crew closes out and egresses the MPLM. The MPLM is then deactivated and utilities to the MPLM are disconnected. The MPLM is then removed from the Node 2 nadir port and replaced back in the Shuttle payload bay using the SSRMS.

The Shuttle then undocks from PMA2 and departs the Station. Following separation, Stage 36 flight mode is LVLH with the Node1/Lab section aligned along the velocity vector.

The "Assembly Complete" configuration is achieved at this stage. The Bus-1's will have to be exchanged in the future to maintain a necessary compliment of propellant on-orbit. The operations required to perform those changeouts are depicted in figures 5.36.3-1 - 5.36.3-3. Figure 5.36.3-1 demonstrates the repositioning of the SSRMS from the MBS to the U.S. Lab to the grapple fixture located on the aft stinger. This repositioning is necessary to facilitate the changeout of the aft Bus-1. Figure 5.36.3-2 depicts the maneuvers required to complete the aft Bus-1 changeout: 1) grapple the "spent" Bus-1 with the SSRMS and hand it to the SRMS; 2) using the SRMS, place the "spent" Bus-1 in the Shuttle payload bay, and grapple the replacement Bus-1; 3) hand-off the Bus-1 from the SRMS to the SSRMS; and, 4) install the replacement Bus-1 on the aft stinger. Figure 5.36.3-3 is a graphical depiction of the similar maneuvers that are required to replace the Bus-1 located in the -Z direction above the Z1 truss. Note that the SSRMS is positioned on the PDGF that is located at (0.0, -4.1, -2.108) meters on the S0 ITS for the zenith Bus-1 swap-out.

System Resource/Functionality

Stage 35 functionality, plus:

- 14 racks delivered and activated
- Assembly complete reached after 19A

Resources Available:	*Power:*	*76,100 W*	
	Thermal:	*TBD*	
	EVA:	*0 crew-hours*	
Resources Required:	*Power:*	*20,983 W*	*(U.S. Housekeeping)*
		TBD W	*(Payload)*
		1,180 W	*(CSA)*
		2,600 W	*(ESA)*
		5,600 W	*(NASDA)*
	Thermal:	*TBD W*	
	EVA:	*0 crew-hours*	

Table 5.36.1-1 Stage 36 - Flight 19A Shuttle Flight Manifest

Hardware	Mass (lbs)	FSE
MPLM-B		10705
US Hab Stowage - HAS6	973	
US Hab Stowage - HAF5	498	
US Hab Refrigerator/freezer/trash - HAC1	982	
US Hab Refrigerator/freezer - HAC2	1304	
US Hab Freezer Rack - HAS3	1325	
US Hab Ward Galley Stowage - HAC3	1400	
US Hab Stowage Rack 1 - HAF2	877	
US Hab Stowage Rack 2 - HAS5	779	
US Hab Stowage Rack 3 - HAP3	779	
US Hab Stowage Rack 4 - HAS2	783	
Node 1 Stowage Rack 4	826	
JEM ELM-PS/US Stowage Rack 2	1473	
APM/US Stowage Rack 1	930	
APM/US Stowage Rack 3	1473	
subtotal	**14402**	**10705**

Shuttle Performance		Mass (lbs)
Capability to 220 n.mi. at 51.6 deg Inclination		24685
Enhancements		13000
Assembly Altitude delta (100 lbs per n.mi.)		-1000
Additional Shuttle Performance Enhancements		0
Variable Integrated Hardware		-1164
Variable Shuttle Consumables		-1055
Additional Crew (500 lbs/crew)	1000	
Food & Gear (-55 lbs/day over 6)	55	
	1055	
Middeck Lockers		-160
Generic Integrated Hardware		-5374
External Airlock	3000	
4th Cryo Tank Fluids	866	
3rd EMU	300	
SAFER	100	
Misc integration hardware	118	
Attach Hardware	990	
	5374	
Weight Growth Reserve		-1730
Maintenance Reserve		-380
Total Shuttle Lift Capability		**26822**

Mission Flight Margin		**1715**

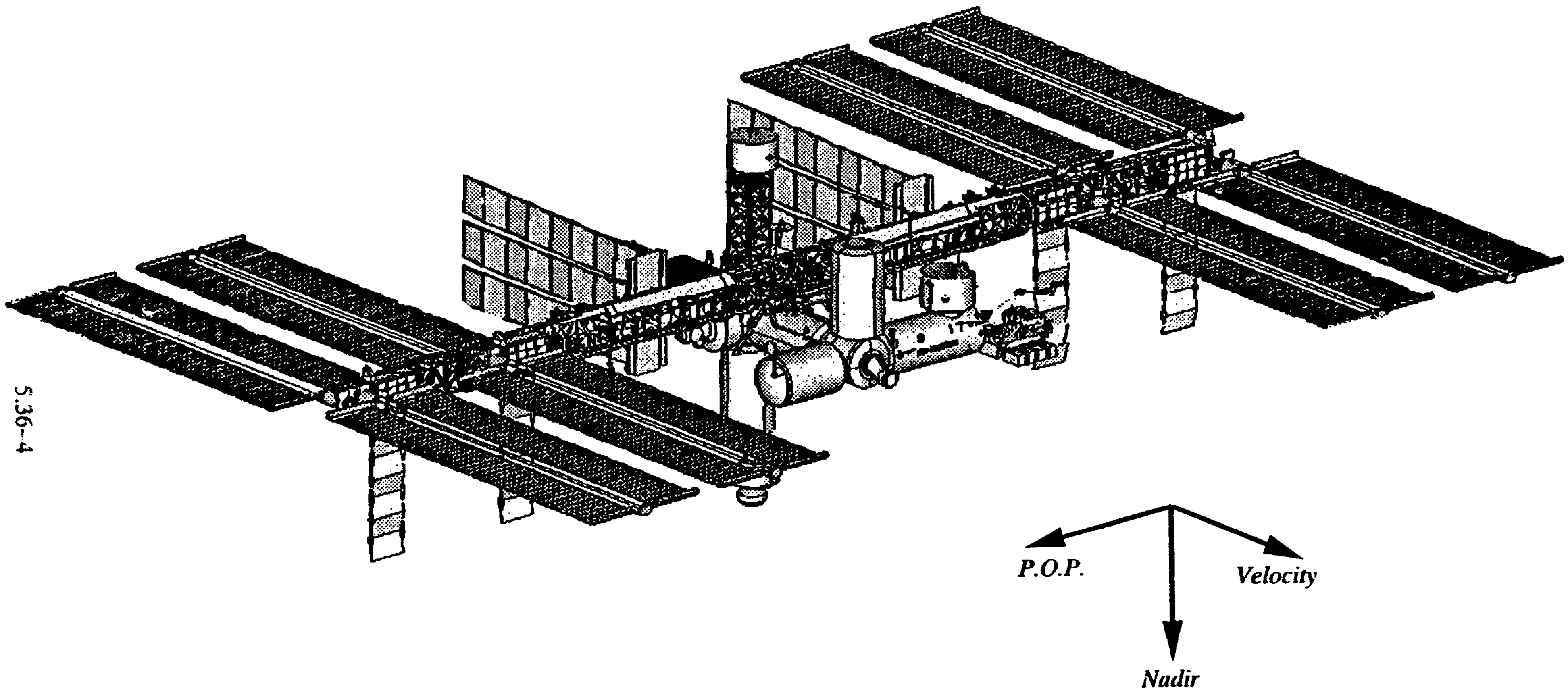


Figure 5.36.2–1 Stage 36 Configuration

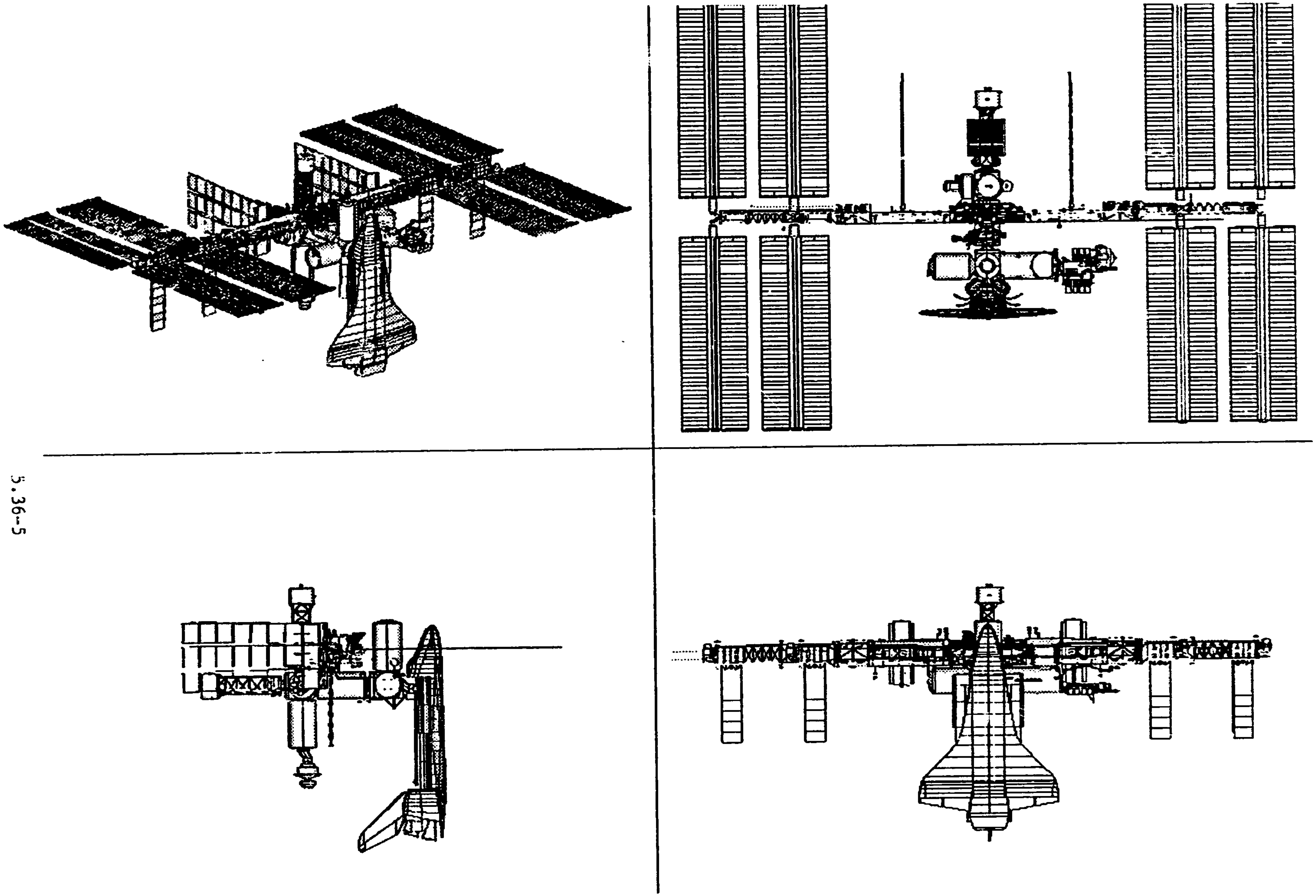


Figure 5.36.2-2 Stage 36 Configuration with Shuttle

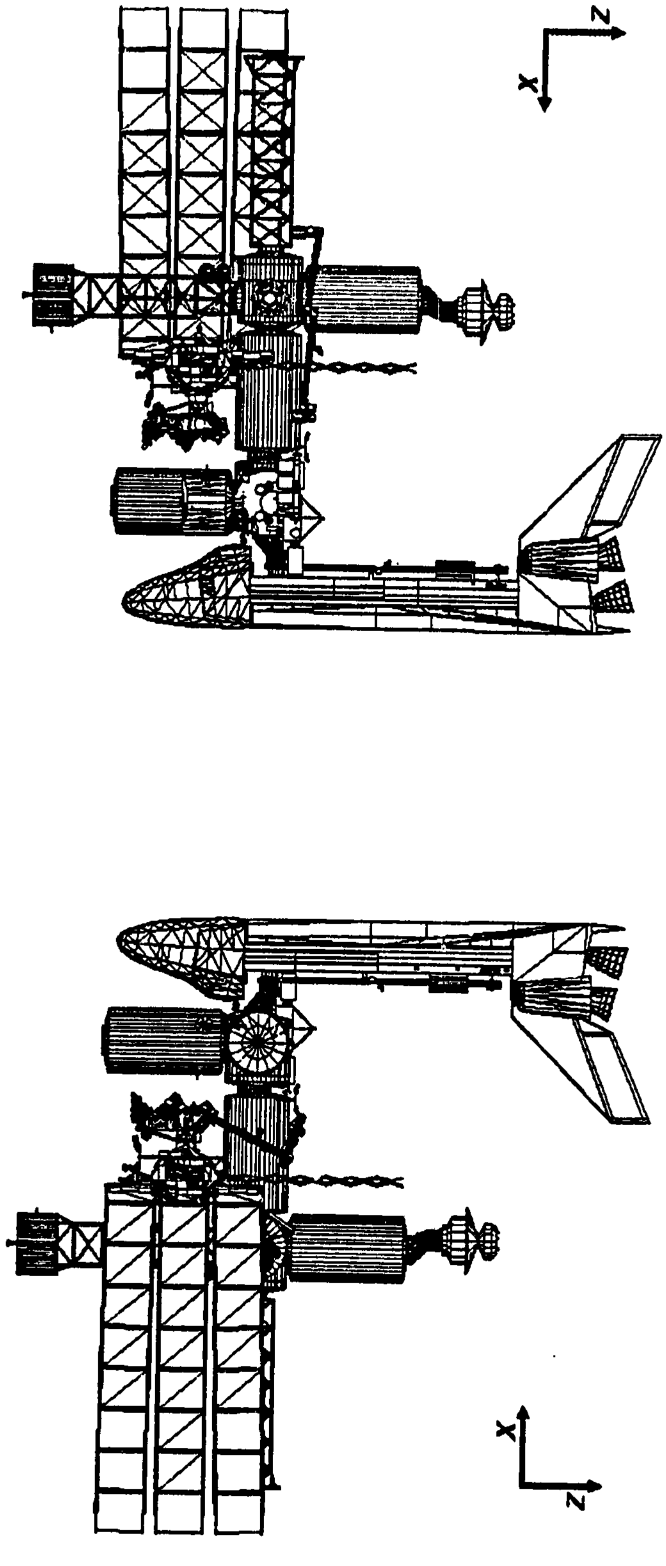


Figure 5.36.3-1 SSRMS Reposition

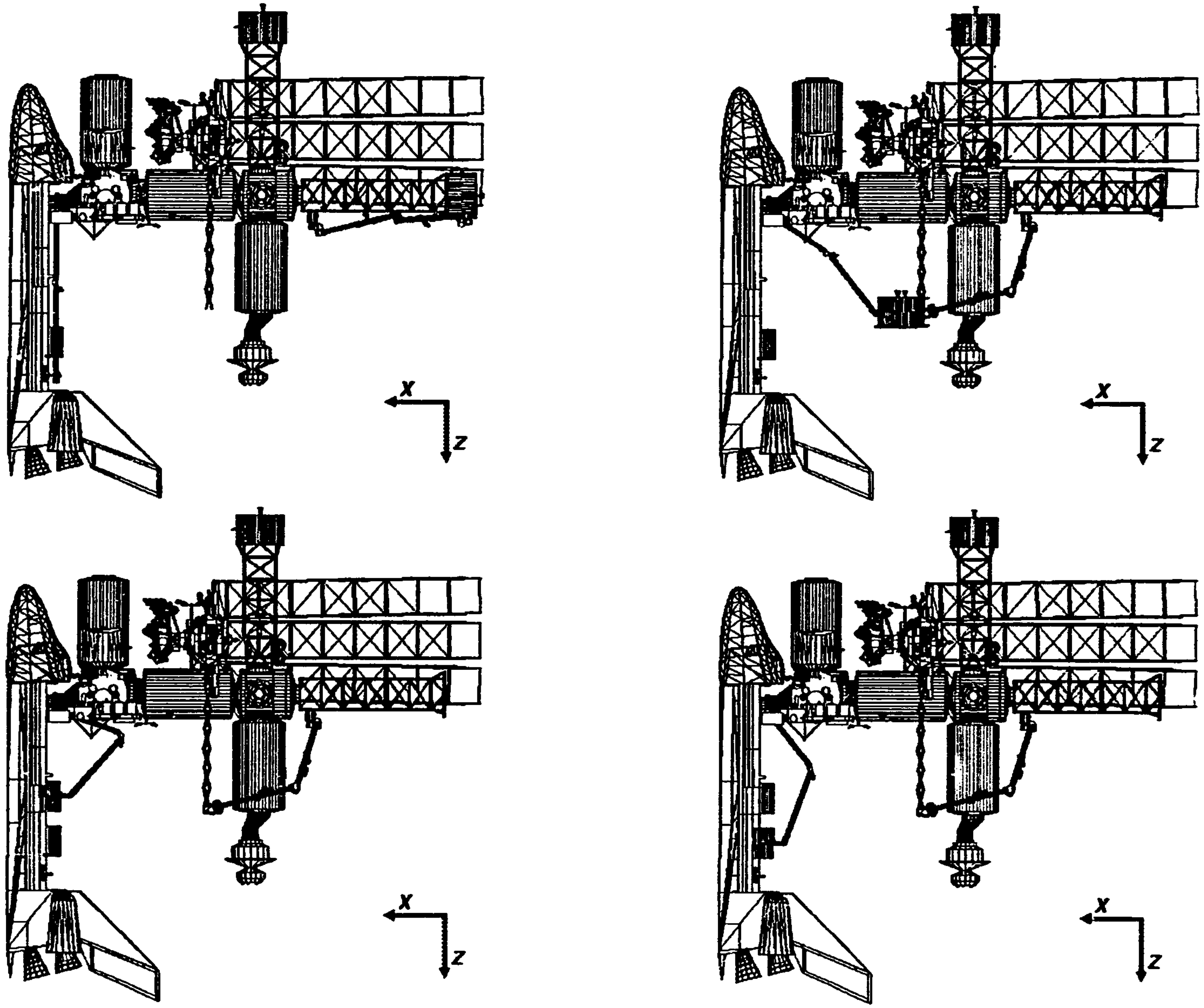


Figure 5.36.3–2 Aft Bus–1 Exchange Operation

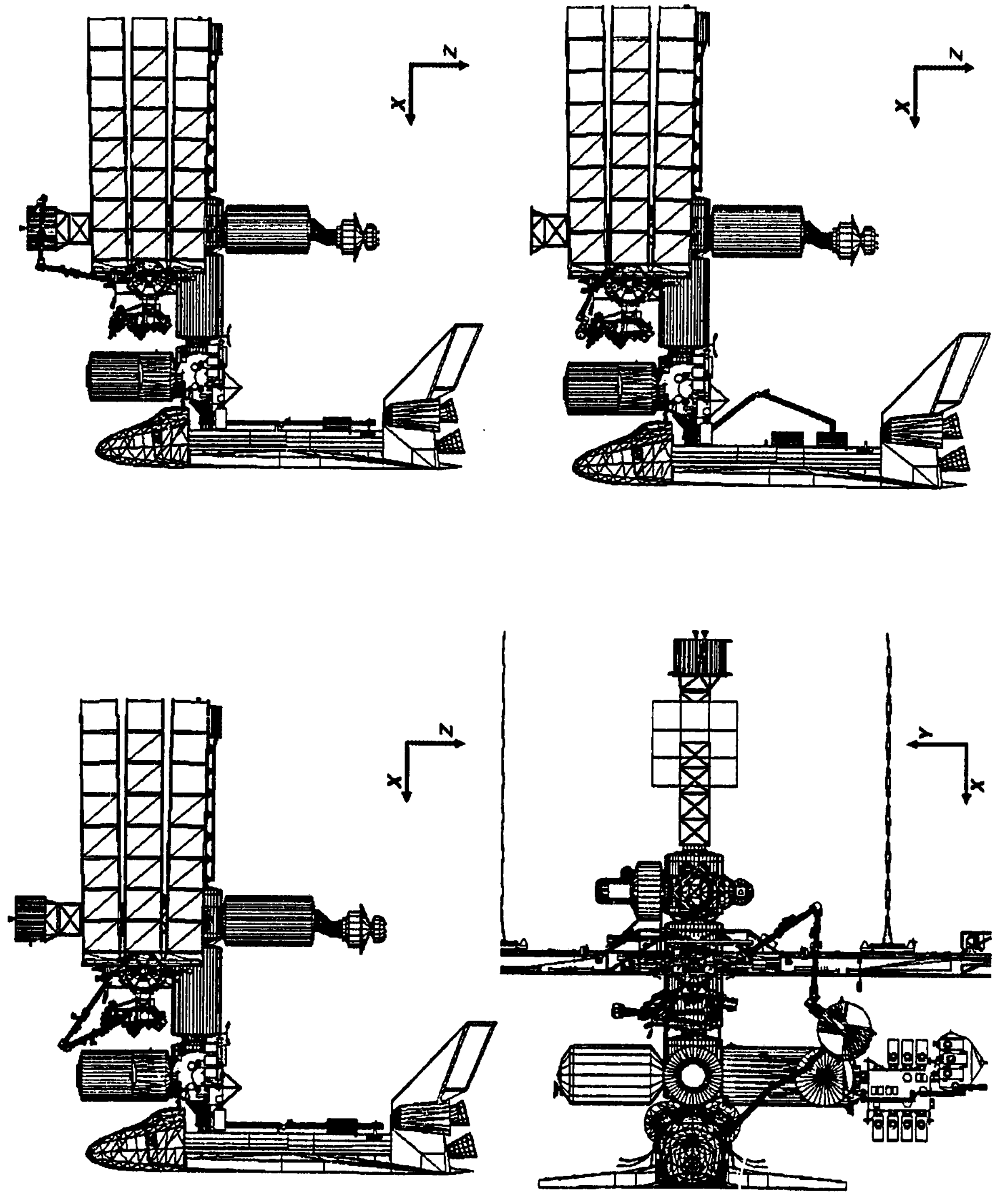


Figure 5.36.3-3 Zenith Bus-1 Exchange Operation

5.36.4 Stage 36, Flight 19A Performance Characteristics

Stage 36, Flight 19A is assembled at a 230 n.mi. altitude in an LVLH flight mode with 4 pairs of double axis articulating PV arrays. The nominal launch date is December, 2003.

Stage 36 in a $+2\sigma$ atmosphere (solar flux = 105.4, geomagnetic index = 19.7) has a flight attitude of yaw =-1.5, pitch = -6.7, and roll = 0.5. The steady state microgravity environment is depicted in figure 5.36.4-1. Table 5.36.4-1 lists the U.S. Laboratory racks, their type, and the maximum steady state microgravity level sensed during the orbit in the given $+2\sigma$ atmosphere. This configuration contains 11 ISPR racks within the 1 μg environment.

Table 5.36.4-1 Stage 36 US Lab Rack Steady State μg Level

Rack	Type	micro-g
LAS-1	ISPR	1.1
LAS-2	ISPR	1.0
LAS-3	ISPR	1.0
LAS-4	ISPR	0.9
LAS-5	SYS	0.9
LAS-6	SYS	0.8
LAF-1	SYS	1.7
LAF-2	SYS	1.7
LAF-3	SYS	1.6
LAF-4	SYS	1.5
LAF-5	SYS	1.5
LAF-6	SYS	1.4
LAP-1	ISPR	1.1
LAP-2	ISPR	1.0
LAP-3	ISPR	0.9
LAP-4	ISPR	0.9
LAP-5	SYS	0.8
LAP-6	SYS	0.7
LAC-1	ISPR	0.4
LAC-2	ISPR	0.4
LAC-3	ISPR	0.3
LAC-4	ISPR	0.3
LAC-5	ISPR	0.2
LAC-6	SYS	0.2

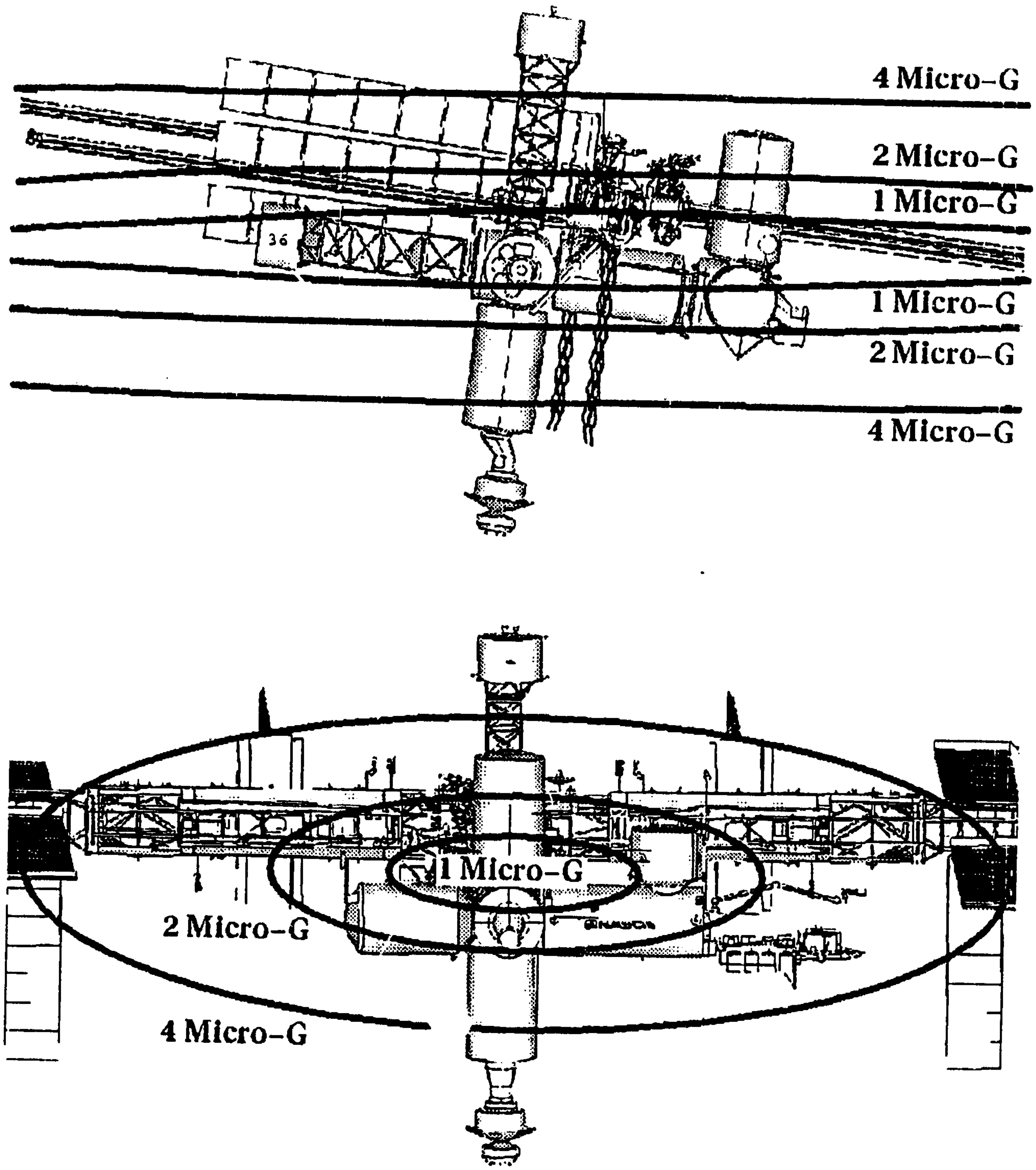


Figure 5.36.4-1 Stage 36 steady-state microgravity contours.

Table 5.36.4-2 summarizes the reboost lifetime characteristics of Stage 36 assuming +2σ atmosphere conditions, an early solar cycle (July 1995 start), and a ballistic coefficient of 11.1 lbs/ft^2. The reboost is performed using the zenith Bus which currently has a reboost efficiency of 85%, while the aft bus has fully expended its propellant load. For this stage there is sufficient propellant reserve on board the station to meet the skip cycle contingency reboost requirement.

Table 5.36.4-2 Reboost Lifetime Characteristics

Rendezvous Altitude (n.mi.)	Reboost Altitude (n.mi.)	Reboost Propellant (lbs.)	Aft Bus Propellant Remaining After Reboost (lbs.)	Zenith Bus Propellant Remaining After Reboost (lbs.)	Lifetime at Rendezvous Altitude (days)
230	234	1,052	-231	14	485

The control characteristics of Stage 36 under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.36.4-2. Table 5.36.4-3 summarizes the control characteristics depicted in the plots.

Table 5.36.4-3 Control Characteristics Summary

Attitude Yaw	Attitude Pitch	Attitude Roll	Maximum Deviation	Peak Momentum
0.0 degrees	-13.5 degrees	0.5 degrees	± 0.5 degrees	9400 N-m-s
0.0 degrees	44.3 degrees	-1.0 degrees	± 0.8 degrees	7200 N-m-s

The control characteristics of Stage 36 (attached Shuttle) under design atmosphere conditions using the PDR nominal controller (attitude emphasis) are displayed in figure 5.36.4-3. Table 5.36.4-3 summarizes the control characteristics depicted in the plots.

As previously discussed in Sections 5.10.4 and 5.17.4 the mated Shuttle and stage configuration must perform periodic attitude maneuvers in order to avoid exceeding thermal loads on the Shuttle during certain solar geometry conditions. The maneuver must be able to be performed using the RCS thrusters from *either* bus starting from Stage 10.

Three sample mated configurations were selected for analysis : Stage 10, when the upper bus is delivered, Stage 17/Flight 12A, and Stage 36/Flight 19A. The CDR RCS attitude maneuver control algorithm was employed. A 180 degree yaw maneuver was performed.

It should be noted that the total impulse per attitude control thruster is 134,000 lb_f-sec.

For Stage 36, a smaller value rate limit was used to prevent excessive overshoot for the more massive Stage 36 configuration, namely, 0.02 degree/sec. The 180 degree yaw maneuver took just under two orbits for both the aft and upper bus. Overshoot was reduced to less than 5 degrees in all channels. The aft bus required 345 lb. of fuel to perform the maneuver, while the upper bus required nearly 370 lb. Once again, all four thrusters on each bus were selected approximately equally by the RCS CDR control algorithm. Table 5.36.4-4 lists the fuel and total impulse requirements.

Table 5.36.4-4 Yaw Maneuver Fuel and Impulse Requirements

Bus	Fuel Used (lb.) / Total Impulse (lb.-sec)				Total Fuel (lb.)
	Nozzle #3	Nozzle #4	Nozzle #5	Nozzle #6	
aft	84.2/24,800	82.9/24,500	89.5/26,400	88.8/26,200	345.5
zenith	90.5/26,700	90.4/26,600	96.0/28,300	93.4/27,500	370.3

5.36.5 Issues and Concerns

This stage has a pitch flight attitude that exceeds ±15 degrees with an attached Shuttle.

There is a possibility of some indirect plume impingement of the aft P6 and S1/P1 radiators from the aft bus attitude control thrusters.

The addition of the CTV eliminates the secondary Shuttle port.

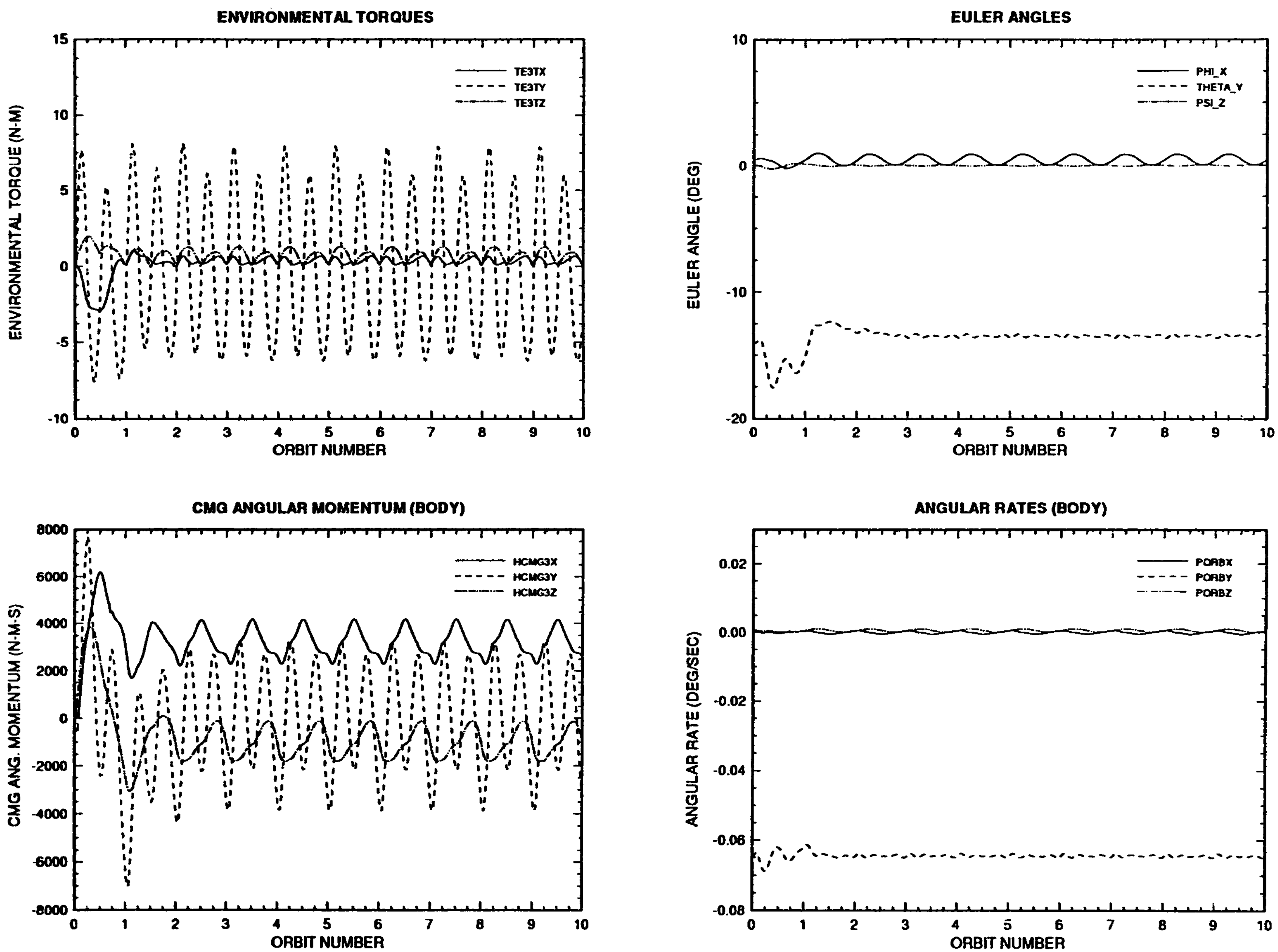


Figure 5.36.4-2 Stage 36 control plots without Shuttle attached.

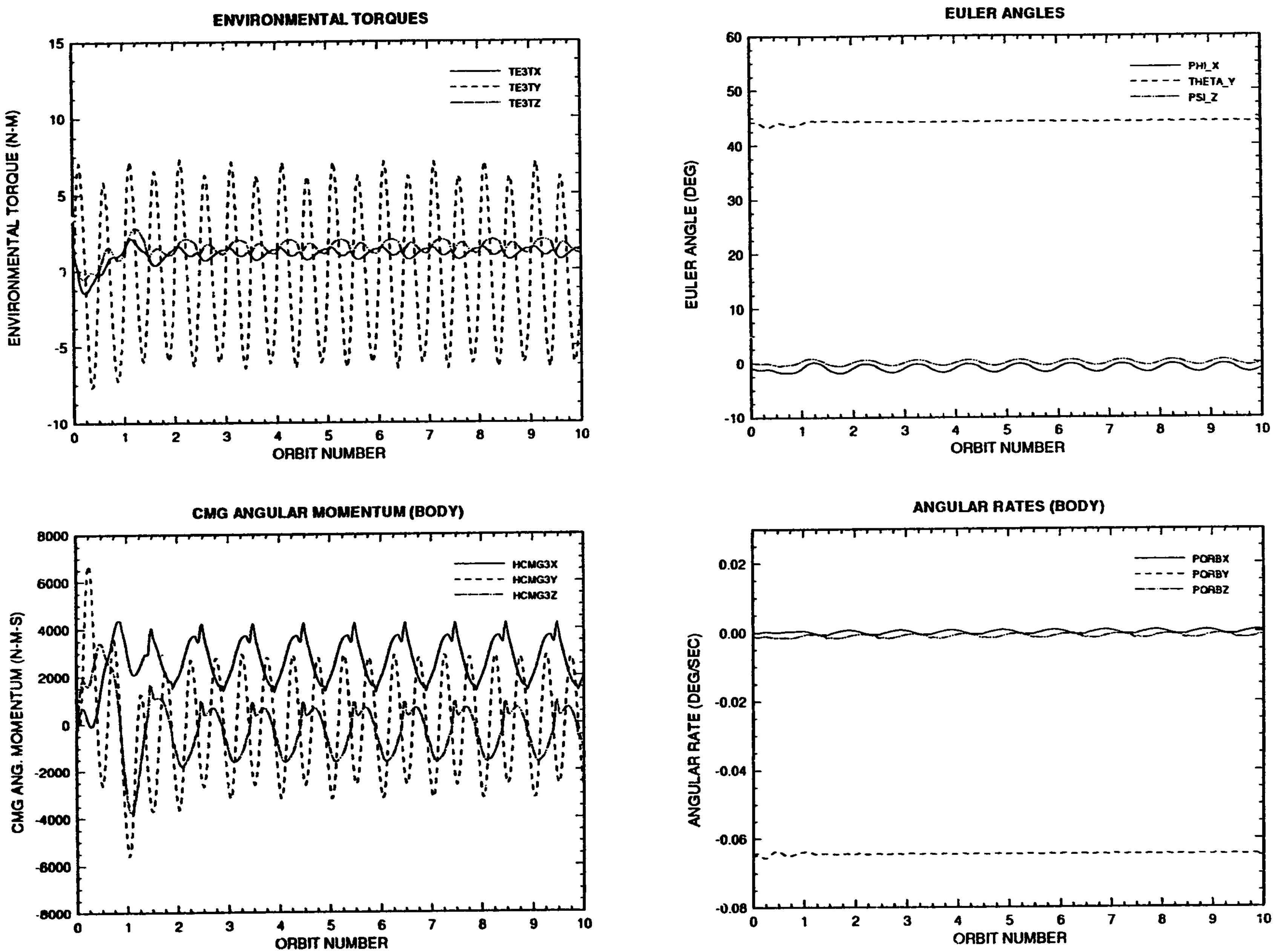


Figure 5.36.4-3 Stage 36 control plots with Shuttle attached.

6. Trend Analyses

6.1 Stage Characterization Analysis

As discussed in Section 4.0: Configuration Mass Properties, several configurations had mass and area distributions which were significantly different from those upon which the CMG attitude control algorithm assumptions were based. As a result, some of the configurations were not controllable with the *Freedom* PDR and CDR control laws. That is not to suggest, however, that they cannot be controlled using CMGs, but rather that customized control algorithms, to take advantage of the mass properties, need to be derived and applied. Such a task was outside the scope and schedule of this analysis.

As discussed in Section 5.4: Performance Characteristics, Stage 1 flies in an arrow flight mode, whereas Stages 2 and 3 are oriented inertially to increase solar power availability. Consequently, Stages 2 and 3 require periodic desaturation.

Stages 4 through 9 are not gravity gradient stable in pitch (Izz > Ixx). Thus the pitch TEA is more negative than the body to principal axis pitch Euler angle. These configurations are characterized by large negative pitch attitudes (see figure 6.1-1). Roll and yaw attitude angles are small, especially due to the use of momentum wheel stabilizers. Stage 5 pitch is more negative than Stage 4, probably due to the fact that the Stage 4 PV arrays are feathered. Stages 5 through 9 are characterized by increasing pitch TEAs as the mass increases, with the exception of Stage 8, where the addition of the airlock actually increases the CP-CG offset, and thus the aerodynamic pitch torque magnitude.

Stages 10 through 13 are characterized by gravity gradient stability in pitch (Ixx > Izz). Thus the torque equilibrium pitch attitude changes sign as the gravity gradient and aerodynamic torques subtract from one another about the equilibrium point. Pitch TEAs vary from +18 to +24 degrees (figure 6.1-1). Beyond Stage 12, the inertias become very nearly equal (figure 6.1-2), which causes problems for the PDR and CDR controllers. These controllers try to take advantage of gravity gradient torques to control attitude. However, the gravity gradient torques become vanishingly small as the inertias become nearly equal. Stages 13 and 15 required momentum wheel supplementation for stability control (Stages 10 -12 did not), while Stages 14 and 16 could not be controlled using any of the available CMG control laws at the design altitude and in the design atmosphere environment.

Stages 17 through 19 could only be controlled using the PDR *yaw bias* control algorithm, which was specifically designed for configurations with Ixx ≈ Izz. The yaw torque equilibrium attitude thus ranges from about +3 to +6 degrees, while the pitch ranges from -1.0 to -1.4 degrees. Stages 17 - 19 were also characterized by the hybrid combination of sun-tracking PV arrays (introduced on Stage 17) and a single axis articulating array (present on Stages 5 through 16).

For the remainder of the Stages starting with Stage 21, again Izz > Ixx (pitch axis gravity gradient unstable), all PV arrays were sun-tracking, and the PDR nominal attitude controller (attitude emphasis) was utilized to successfully control attitude. The pitch TEA hovered in the -5 to +3 degree range, with the exception of Stages 35 and 36, which had pitch TEAs of -13 degrees (figure 6.1-1).

In summary, the early LVLH Stages (*viz.*, S4 to S9) were characterized by poor gravity gradient pitch axis stability characteristics, resulting in large pitch torque equilibrium attitudes. Stages 10 through 13 were characterized by large positive pitch TEAs, while Stage 14 and 16 could not be controlled using the PDR/CDR CMG control algorithms. Stages 17 and beyond were all controllable, although Stages 17 through 19 required a yaw bias controller due to nearly equal moments of inertia.

The torque equilibrium attitude of the mated Station/Shuttle stack is dominated by the presence of the STS, especially during the early stages. Principal to body axis pitch angles vary from -40 degrees to +45 degrees. Figure 6.1-3 shows the variation in principal moments of inertia during the assembly build sequence. Notice that Stage 5 has Izz > Ixx (gravity gradient unstable), which may explain why neither the PDR nor CDR CMG control algorithms were able to maintain attitude while managing angular momentum build-up.

Consistent with the principal to body axis rotation angles, the pitch TEA attitudes were quite large. Figure 6.1-4 shows the variation in pitch TEA over the assembly build sequence. Although all stages were controllable beyond Stage 5, pitch attitudes hovered around the ±40 degree range. It is speculated that in some cases, a pitch TEA on either side of zero degrees would give comparable performance.

By and large, the PDR CMG control algorithm was successfully used for attitude control of the mated configurations throughout the assembly sequence. Notable exceptions was 16, which used the JSC/UT algorithm. Stages 17 and 19 required tne use of a 10,000 N-m-s momentum wheel for additional stability augmentation. Attitude oscillations were usually less than ±2 degrees. Peak angular momentum requirements were well within CMG capacity for most of the stages. Only Stages 19 through 27 required in excess of 10,000 N-m-s of capacity, with Stage 19 momentum requirements just exceeding the 18,980 N-m-s CMG capacity.

Reboost efficiency analyses were performed on both buses for Stages 4 through 36. The tabulated results shown in tables 6.1-1 and 6.1-2 list the reboost efficiency, the reboost engine used, and the thruster gimbal yaw and pitch angles for each stage (refer to figures 3.3-2 and 3.3-3 for reboost engine locations). The station attitude is approximately equal and opposite to the thruster gimbal yaw and pitch angles. Also, note that when the maximum thruster gimbal angle was reached, the reboost efficiency was less than 100%.

Analysis shows that the aft bus, located on the end of the x-axis truss extension, maintains 100% reboost efficiency for Stages 7-9 and Stages 22-36. Efficiency drops below 100% for Stages 4-6 and Stages 10-21 due to the station center of gravity (C.G.) migrating outside of the reboost thruster gimbal range, as shown in figures 6.1-5 and 6.1-8. Stage 4 possesses the lowest aft bus efficiency level of 86.7%. The C.G. migration responsible for the efficiency decreases is in the body z-axis direction. Migration in the body x-axis and y-axis directions, as shown in figures 6.1-6 and 6.1-9, does not impact the reboost efficiency of aft bus for Stages 4-21. Figures 6.1-11 and 6.1-12 show C.G. migrations for Stages 22-36 in relation to the aft bus thruster gimbal range. All the center of gravity locations are within the gimbal range of the aft bus for these stages.

Reboost efficiency for the zenith bus is 100% from Stage 10, when the Bus-1 and z-axis truss extension are added to the Station, until Stage 21. The C.G. migration for these stages is shown in figures 6.1-7 and 6.1-8. During Stage 22 operations, the zenith bus is moved closer to the station origin, due to the transfer of the P6 truss segment to the port

side of the transverse boom. This results in C.G. locations which are outside of the zenith bus reboost thruster gimbal limits, as shown in figures 6.1-10 and 6.1-11. The station C.G. locations for Stages 22-36 are all outside the gimbal range in the x-direction, while Stages 22-27 are also outside in the y-direction. Reboost efficiency drops to a low of 76.7% for Stage 27 and increases somewhat for later stages. However, efficiency is only 85.2% for Stage 36.

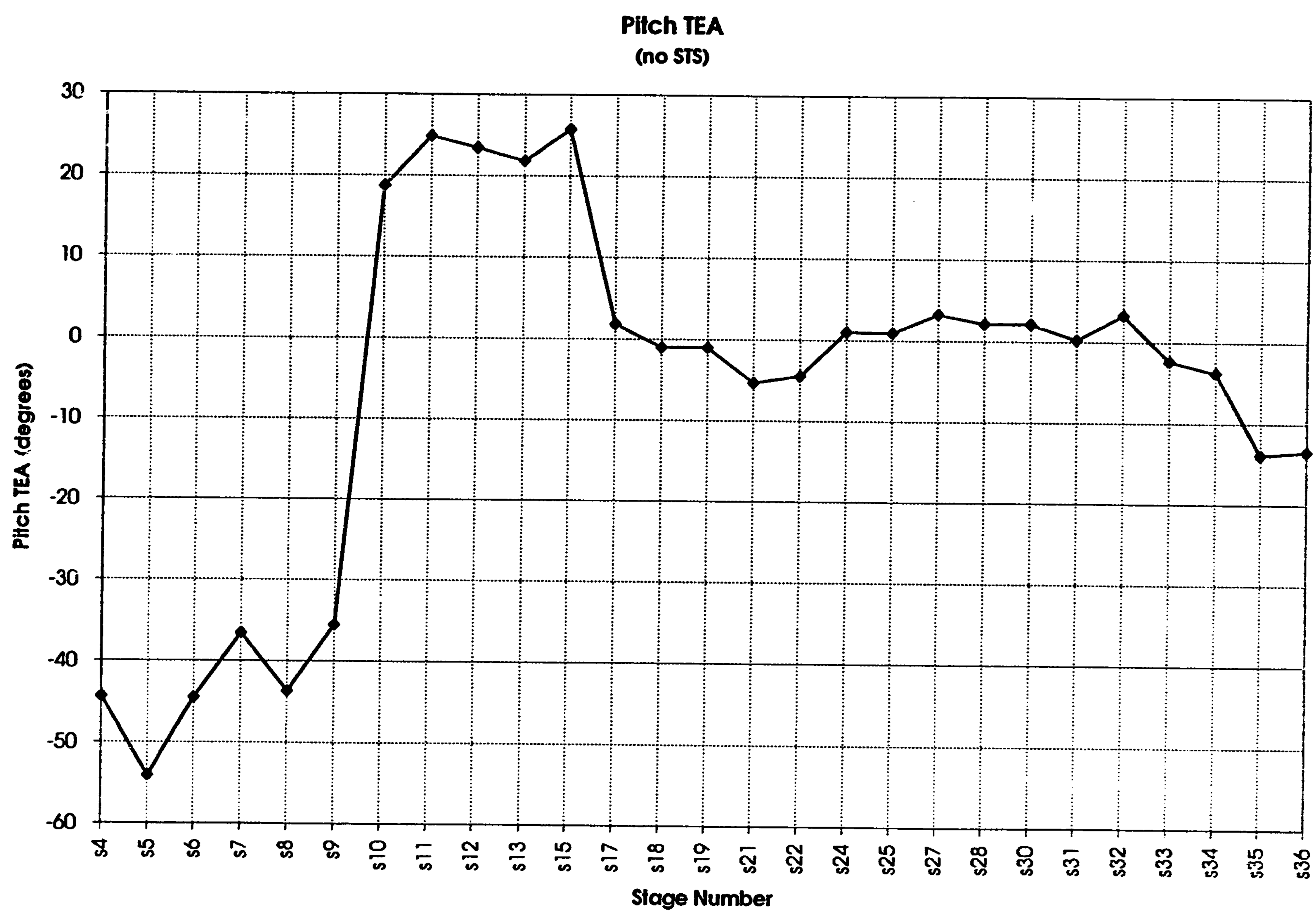


Figure 6.1-1 Pitch TEA without Shuttle Attached

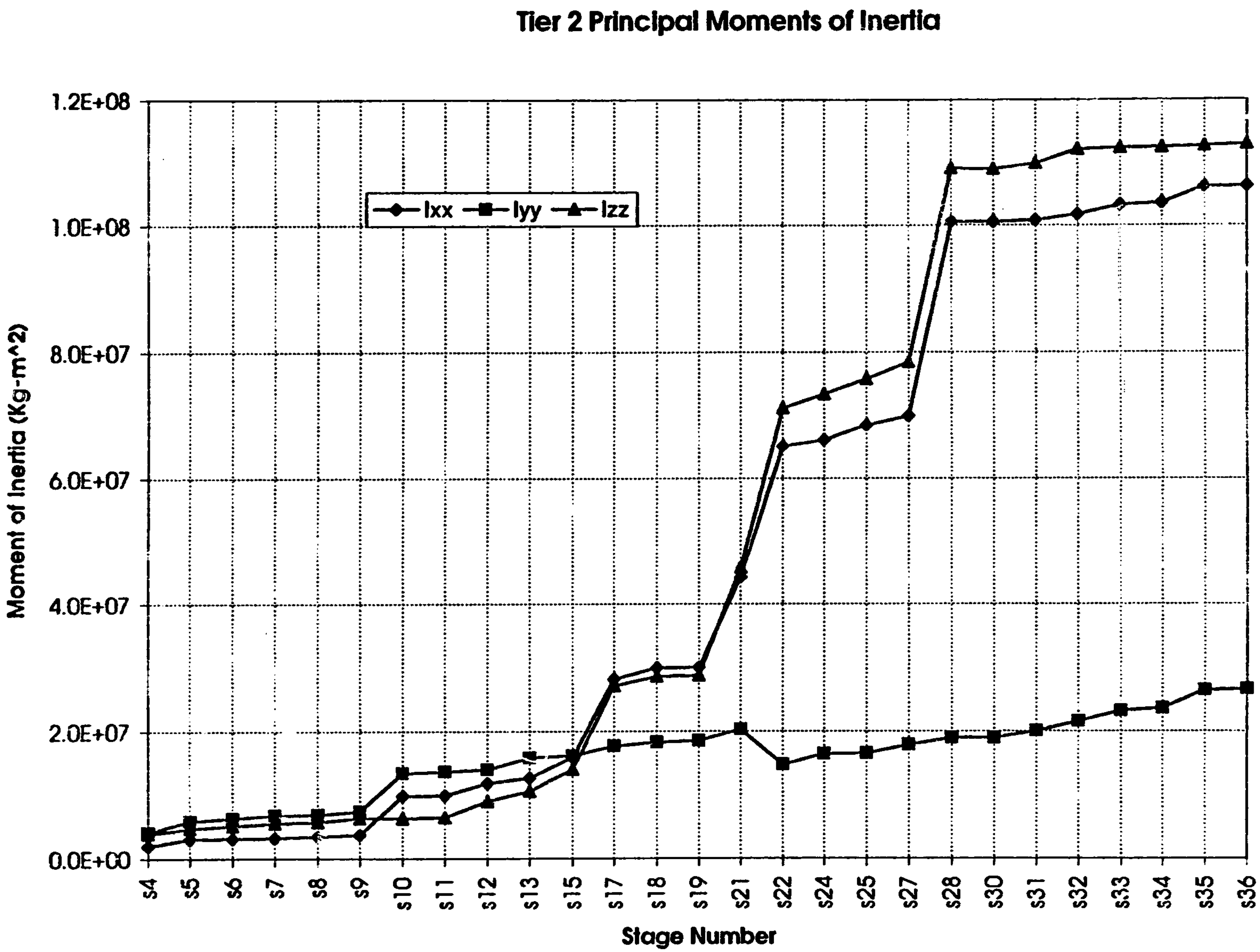


Figure 6.1-2 Principal Moments of Inertia without Shuttle Attached

Tier 2 Principal Moments of Inertia
(Attached STS)

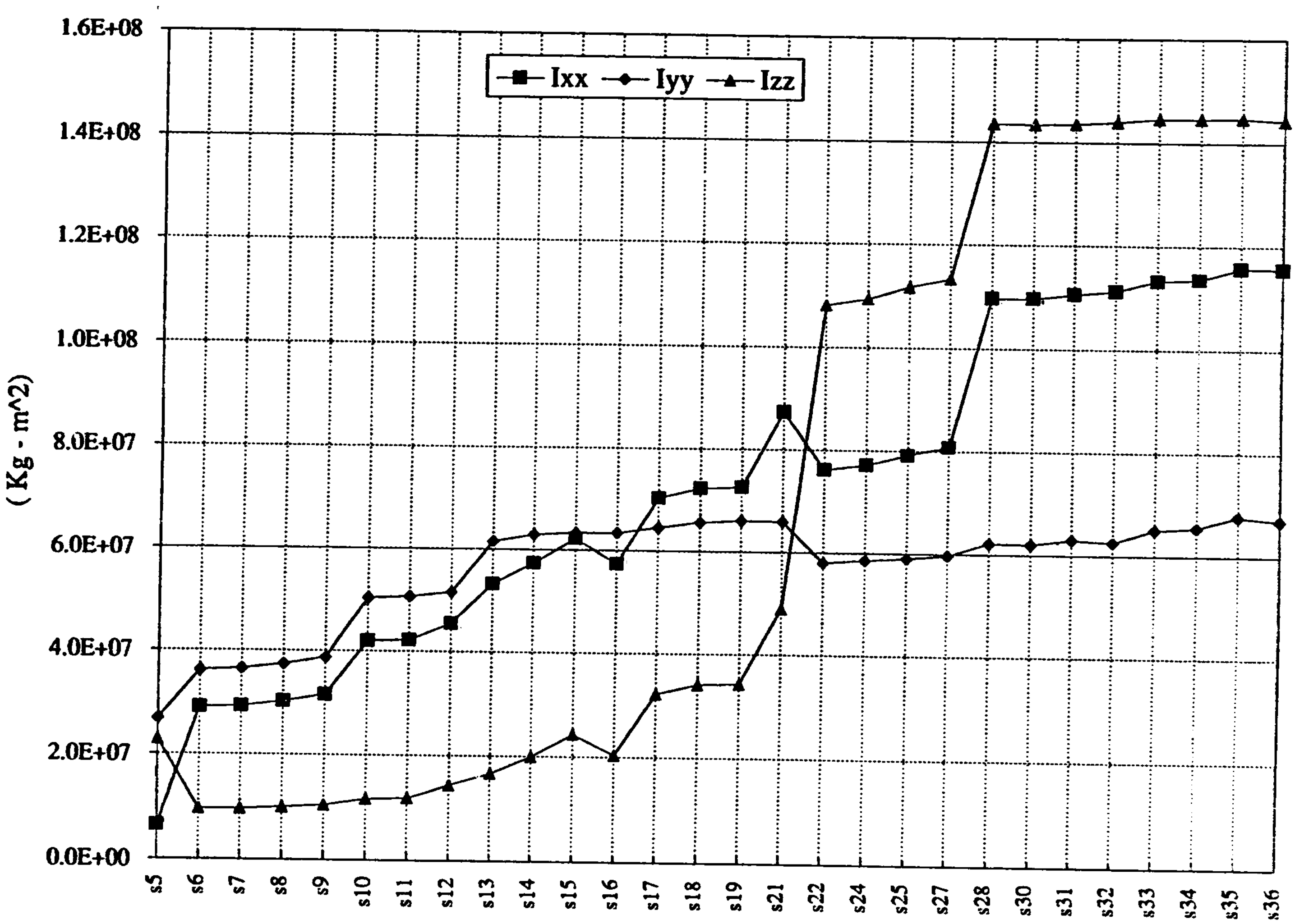


Figure 6.1-3 Principal Moments of Inertia with Shuttle Attached

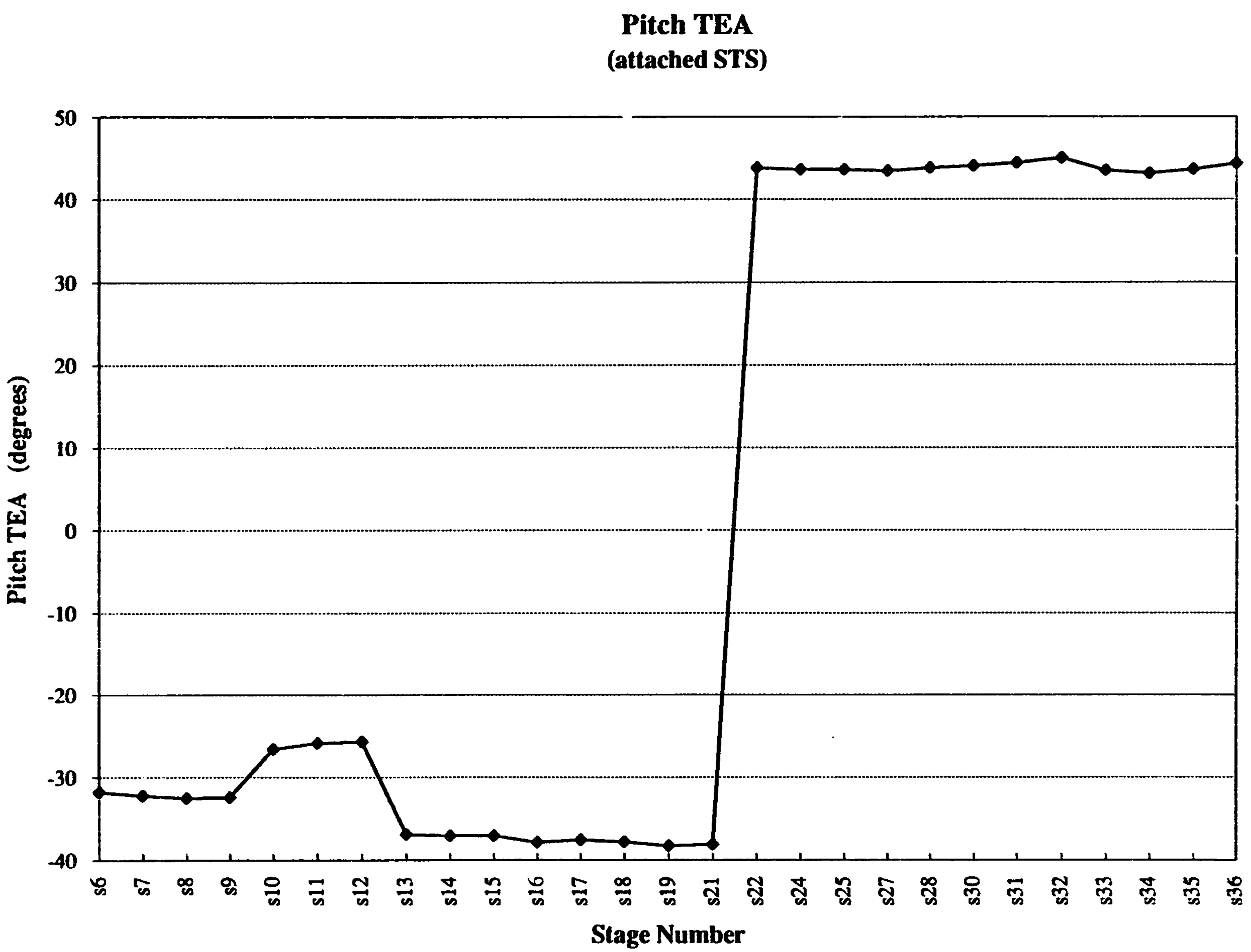


Figure 6.1-4 Pitch TEA with Shuttle Attached

Table 6.1-1 Aft Bus-1 Efficiency Chart

Stage	Reboost Efficiency	Reboost Engine Used (1 or 2)	Thruster Gimbal Angle (deg.)	
			Yaw	Pitch
4	86.69%	1	3.57	10.00
5	96.47%	2	-0.14	10.00
6	98.51%	1	2.28	10.00
7	100.00%	1	2.15	9.46
8	100.00%	1	3.74	8.41
9	100.00%	1	3.46	9.00
10	87.87%	1	3.84	10.00
11	88.50%	1	3.94	10.00
12	88.96%	1	8.23	10.00
13	92.33%	1	7.15	10.00
14	92.28%	1	3.12	10.00
15	92.20%	1	3.13	10.00
16	93.08%	1	2.97	10.00
17	93.84%	2	-6.52	10.00
18	93.55%	2	-7.21	10.00
19	93.42%	2	-7.25	10.00
20	93.42%	2	-7.25	10.00
21	93.54%	1	2.73	10.00
22	100.00%	1	-7.21	9.65
23	100.00%	1	-7.21	9.65
24	100.00%	1	-8.71	8.51
25	100.00%	1	-7.93	8.55
26	100.00%	1	-7.93	8.55
27	100.00%	1	-8.98	7.84
28	100.00%	1	-1.75	8.16
29	100.00%	1	-1.75	8.16
30	100.00%	1	-1.70	8.16
31	100.00%	1	-1.52	8.38
32	100.00%	1	-0.37	7.69
33	100.00%	1	-0.28	6.63
34	100.00%	1	-0.25	6.36
35	100.00%	1	-0.18	4.89
36	100.00%	1	-0.16	4.87

Table 6.1-2 Zenith Bus-1 Efficiency Chart

Stage	Reboost Efficiency	Reboost Engine Used (1 or 2)	Thruster Gimbal Angle (deg.) Yaw	Pitch
10	100.00%	1	2.46	0.56
11	100.00%	1	2.57	0.77
12	100.00%	1	6.22	2.45
13	100.00%	1	5.65	4.88
14	100.00%	1	2.28	5.22
15	100.00%	1	2.28	5.24
16	100.00%	1	2.25	6.69
17	100.00%	1	-3.62	6.51
18	100.00%	1	-4.31	7.17
19	100.00%	1	-4.31	6.92
20	100.00%	1	-4.31	6.92
21	100.00%	1	2.05	6.50
22	91.74%	1	-10.00	10.00
23	91.74%	1	-10.00	10.00
24	80.21%	1	-10.00	10.00
25	84.19%	1	-10.00	10.00
26	84.19%	1	-10.00	10.00
27	76.70%	1	-10.00	10.00
28	86.04%	2	-6.27	10.00
29	86.04%	2	-6.27	10.00
30	86.15%	2	-6.19	10.00
31	83.66%	2	-6.14	10.00
32	80.91%	2	-4.51	10.00
33	83.24%	2	-4.11	10.00
34	83.79%	2	-4.01	10.00
35	85.58%	2	-3.66	10.00
36	85.17%	1	0.63	10.00

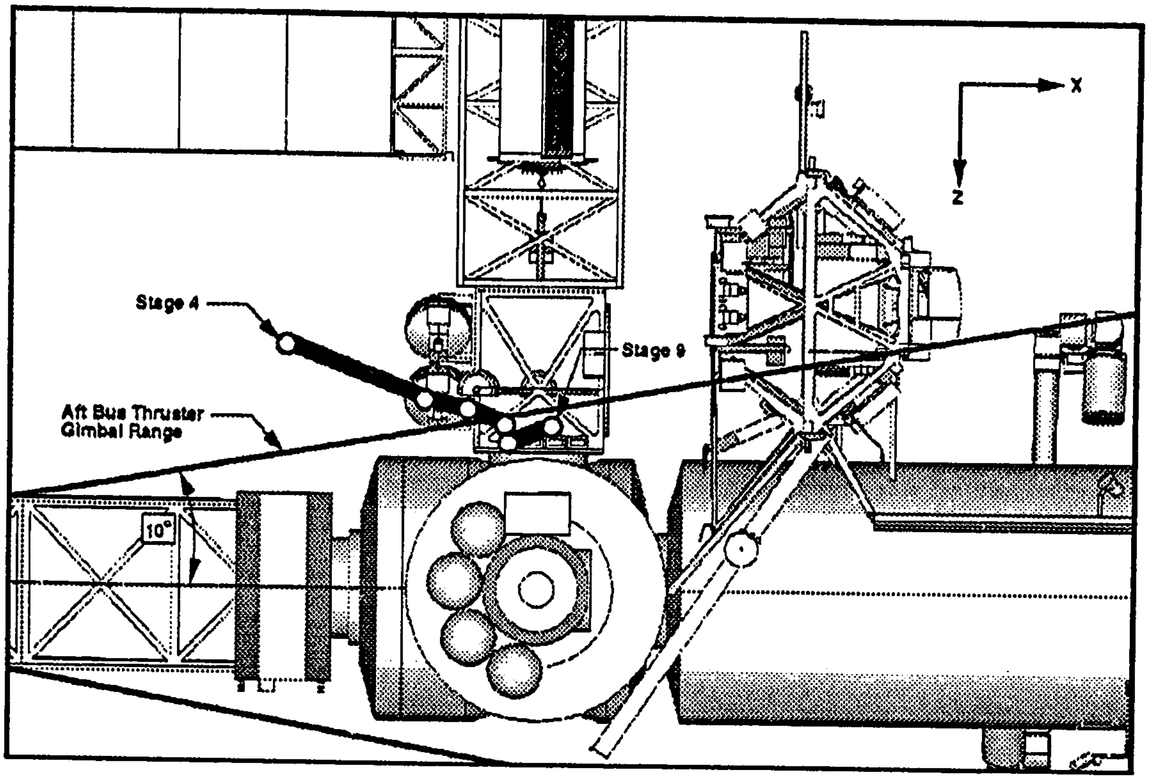


Figure 6.1-5 Y-axis view of station center of gravity for Stage 4 through Stage 9.

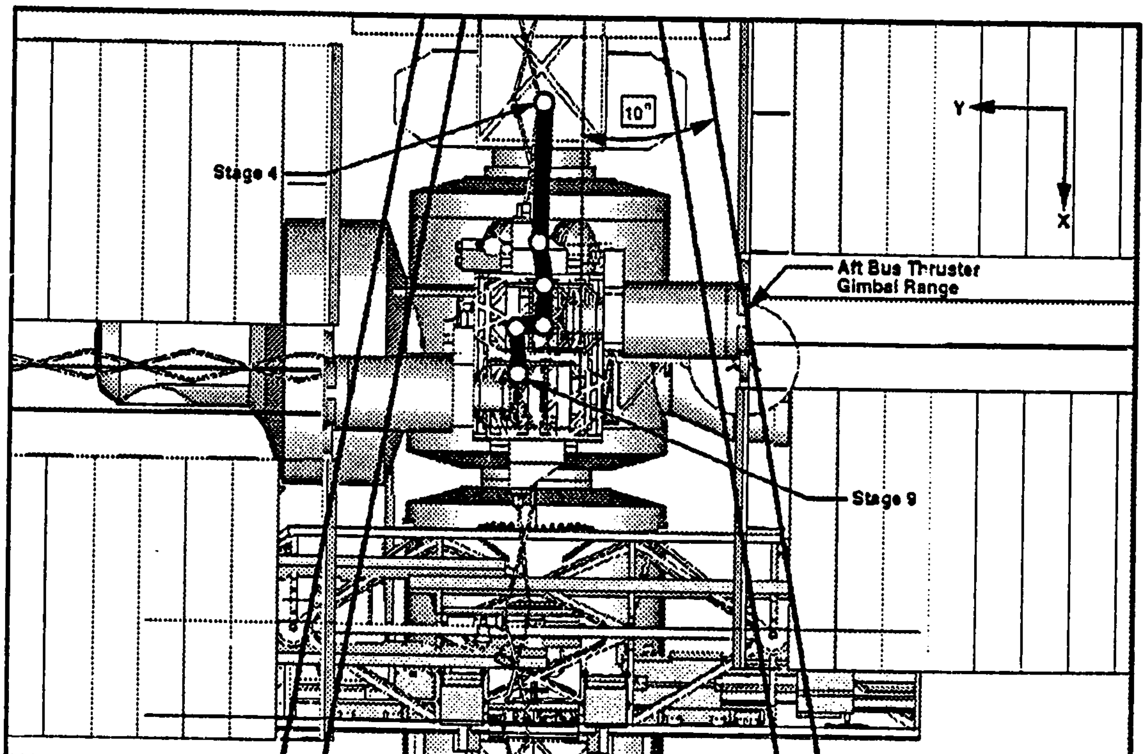


Figure 6.1-6 Z-axis view of station center of gravity for Stage 4 through Stage 9.

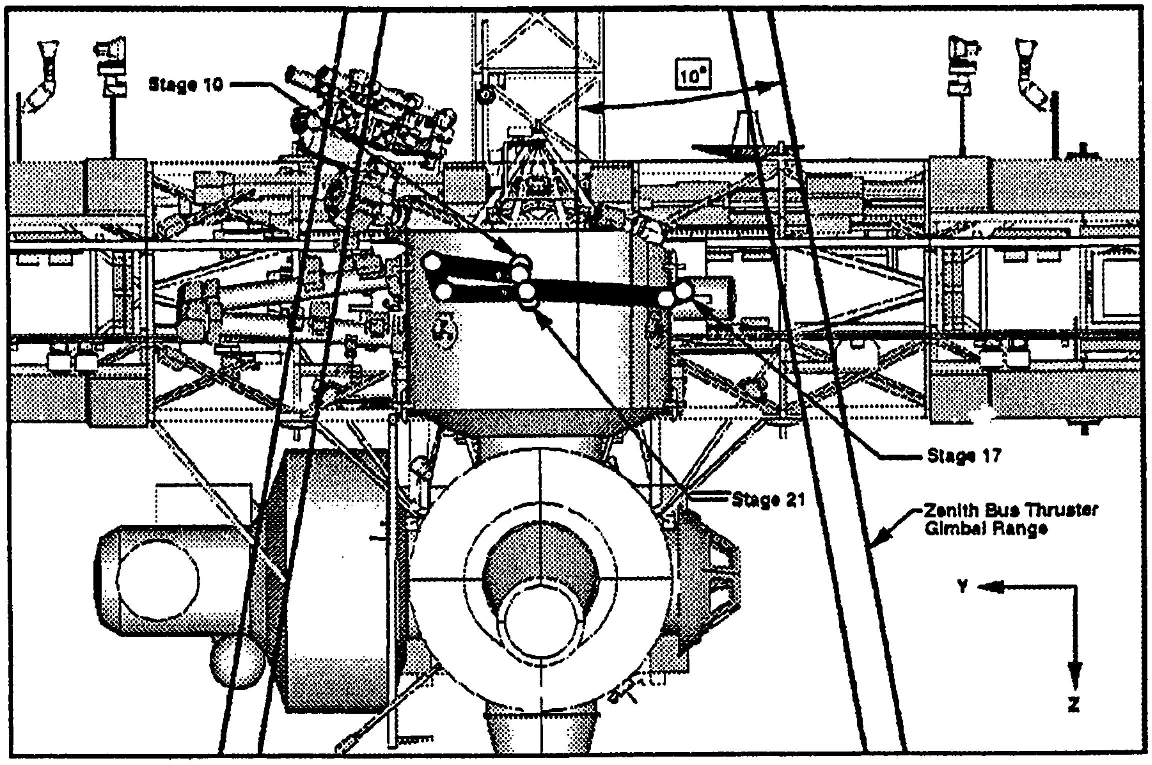


Figure 6.1-7 X-axis view of station center of gravity for Stage 10 through Stage 21.

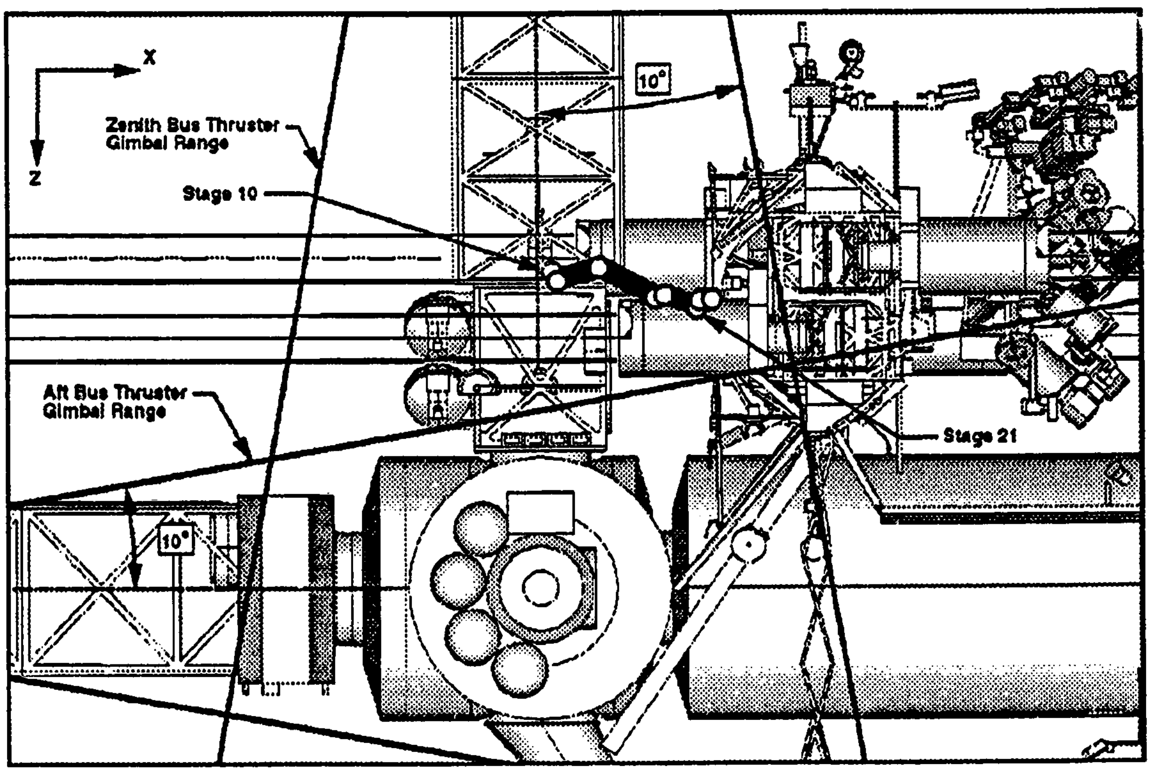


Figure 6.1-8 Y-axis view of station center of gravity for Stage 10 through Stage 21.

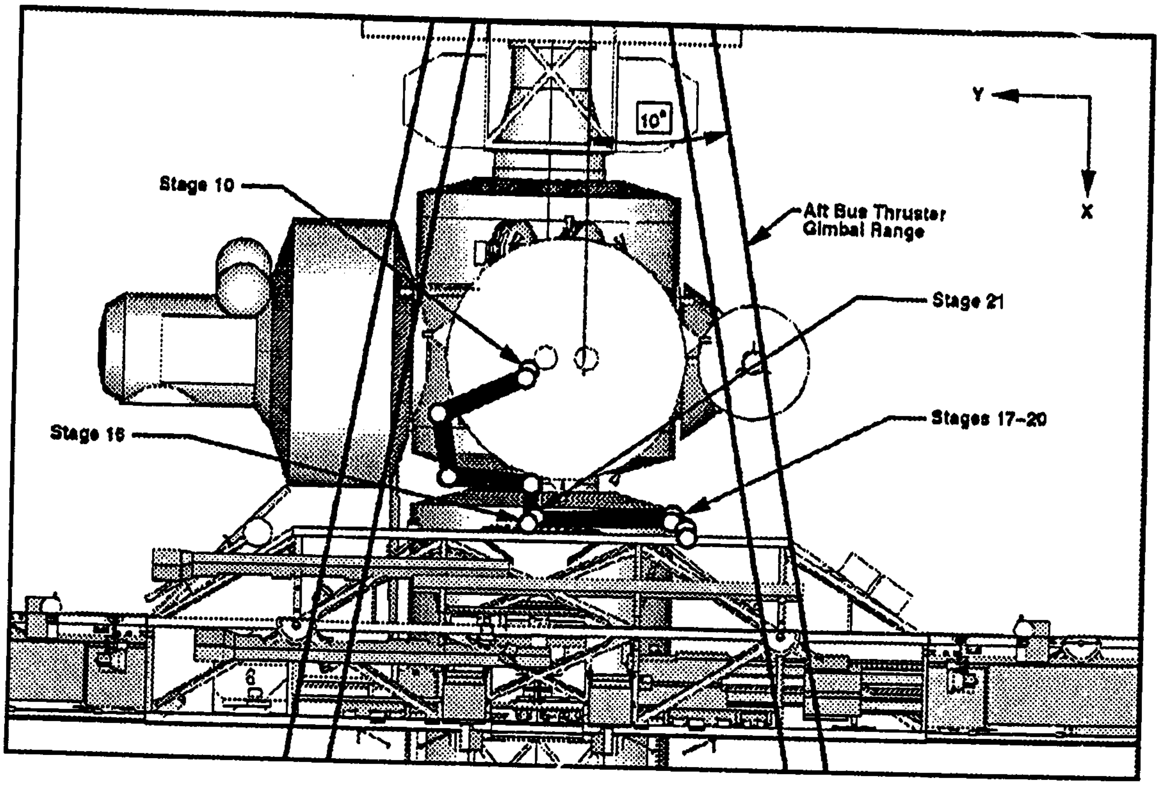


Figure 6.1-9 Z-axis view of station center of gravity for Stage 10 through Stage 21.

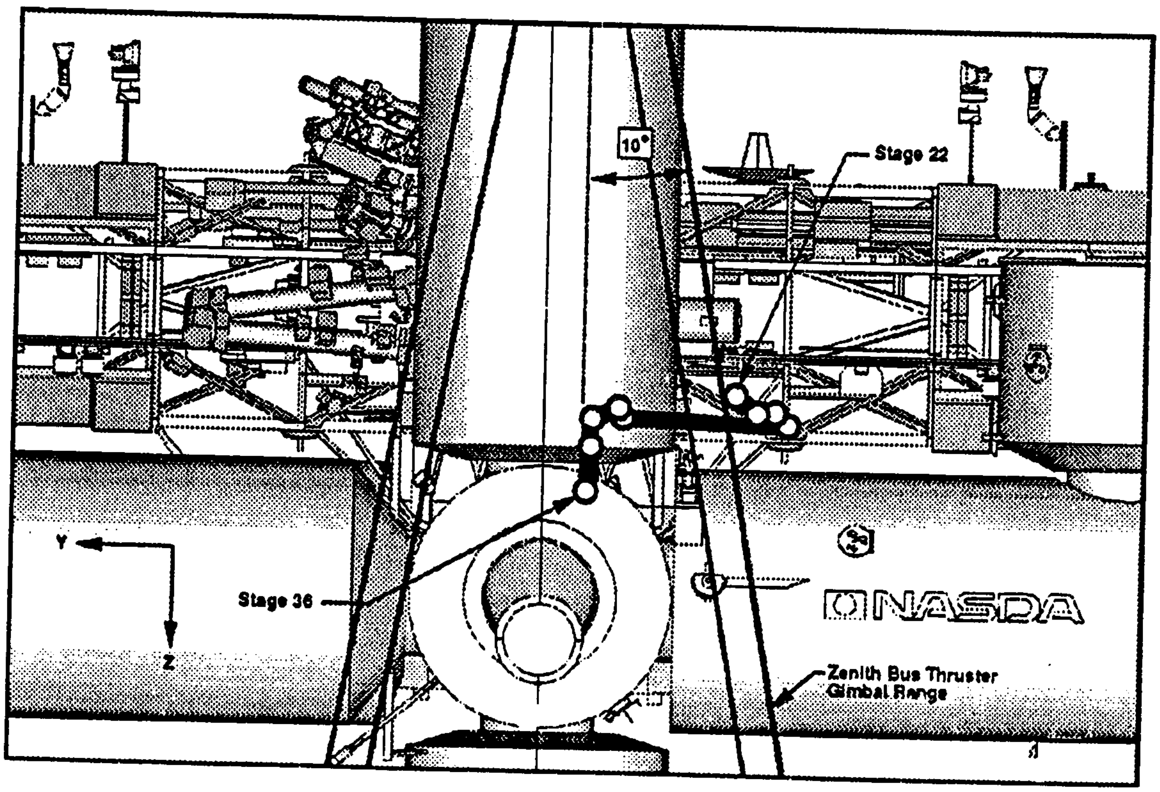


Figure 6.1-10 X-axis view of station center of gravity for Stage 22 through Stage 36.

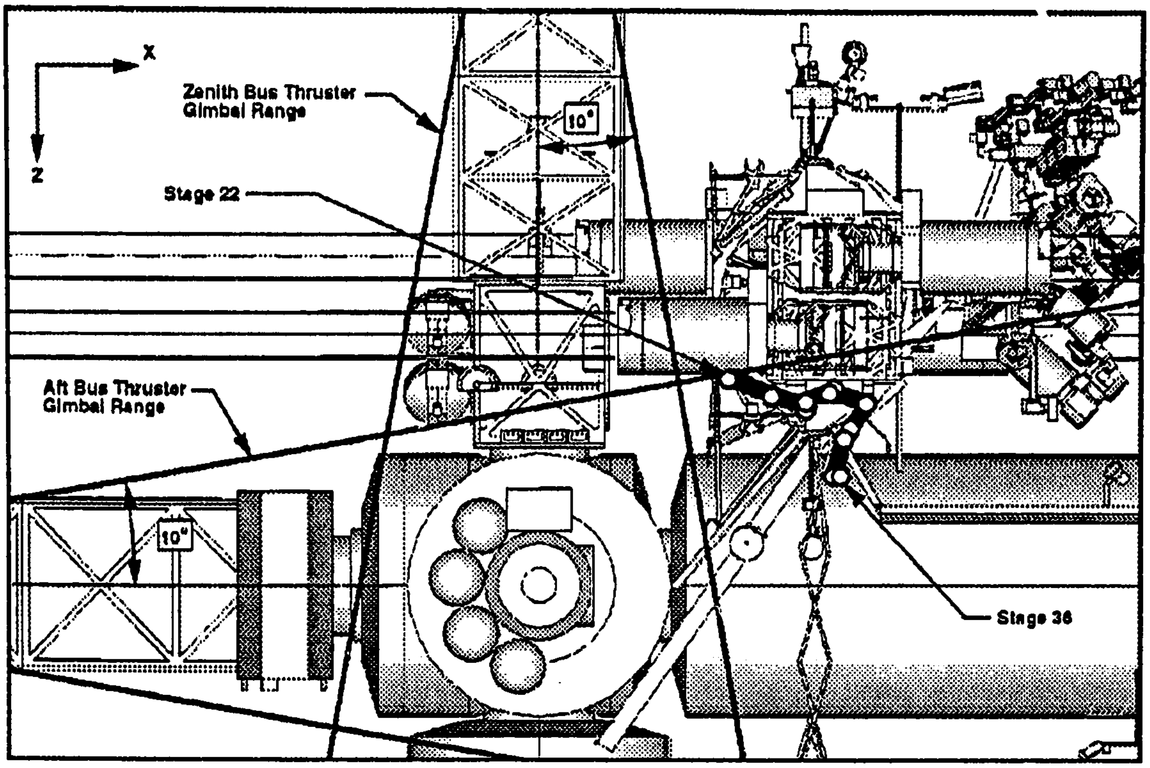


Figure 6.1-11 Y-axis view of station center of gravity for Stage 22 through Stage 36.

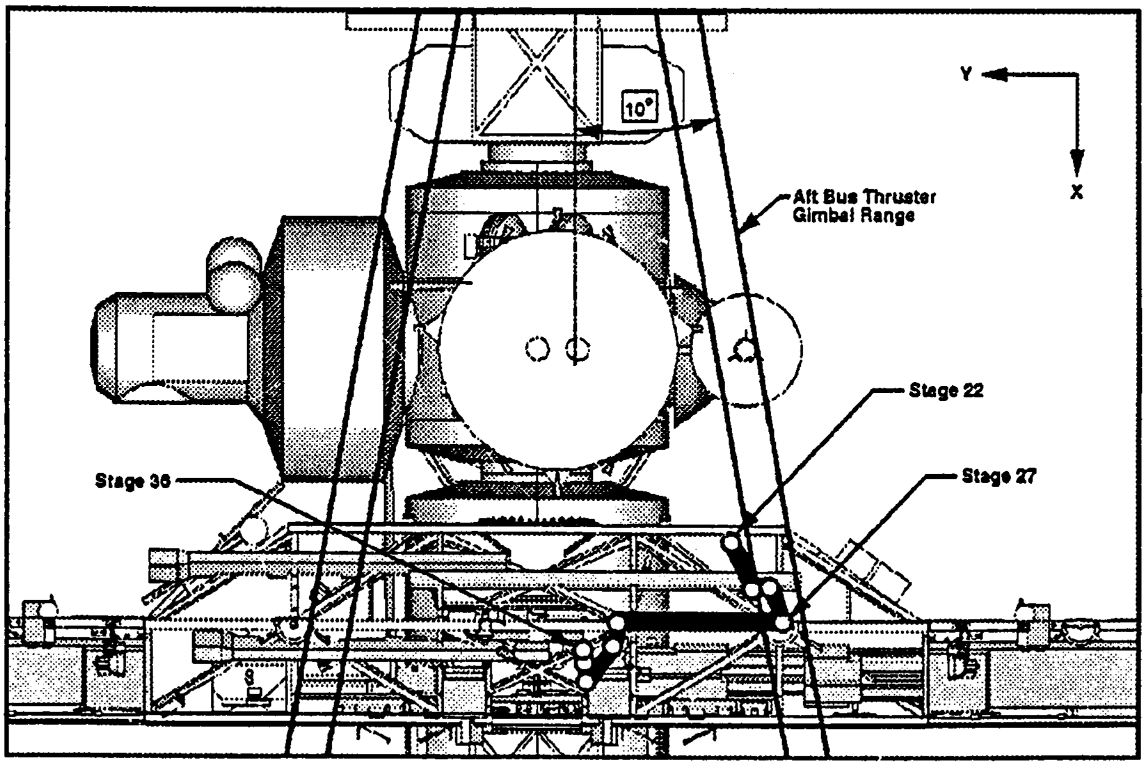


Figure 6.1-12 Z-axis view of station center of gravity for Stage 22 through Stage 36.

6.2 Resource Trends

6.2.1 Power

Figure 6.2-1 provides a comparison of the U.S. Housekeeping and International Partner Power Requirements to the Power Generated. The stage power margin is also included.

6.2.2 Thermal

TBD

6.2.3 Extra-Vehicular Activity

Figure 6.2-2 provides a comparison of the Assembly EVA-hours Available to the Assembly EVA-hours Required. Appendix B lists all of the EVA tasks, including an estimate of the time, necessary to complete the assembly of the station.

The most demanding phase of the assembly sequence occurs between Flight 1 J/A and Flight 13A+. Those flights involve assembling the inboard port and starboard power modules (P3/4 and S3/4), and relocating the P6 power module to its final location. Flight 12A and 13A are constrained to 2 EVAs per flight, while the baseline number of EVAs on those flights is 5 and 6, respectively. This drove the addition of Flights 12A+ and 13A+ to accommodate the backlog of EVAs from those flights. The main effect of that issue was to delay the operation of the PV modules by one flight each.

To the greatest extent possible, there are no planned EVAs on any of the Utilization Flights except UF-2 (single EVA). This is a ground rule that was accepted at the beginning of the study.

There are no EVAs dedicated to external maintenance in this scenario. This is something that needs to be addressed immediately, particularly because there is no station-based crew prior to Assembly Complete that could begin working off maintenance items.

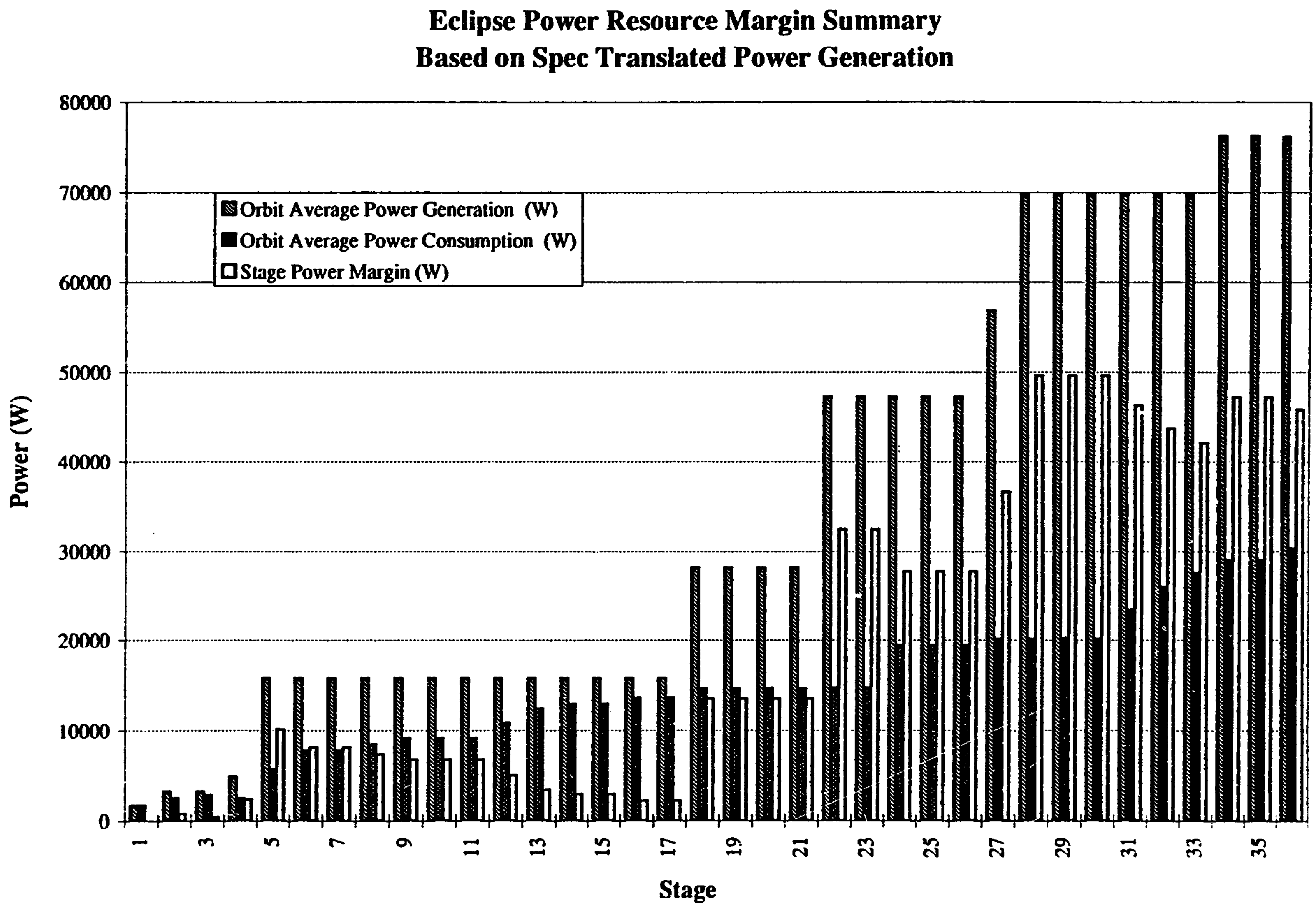


Figure 6.2-1 Comparison of U.S. Housekeeping and Internation Partner Power Requirements to the Power Generated

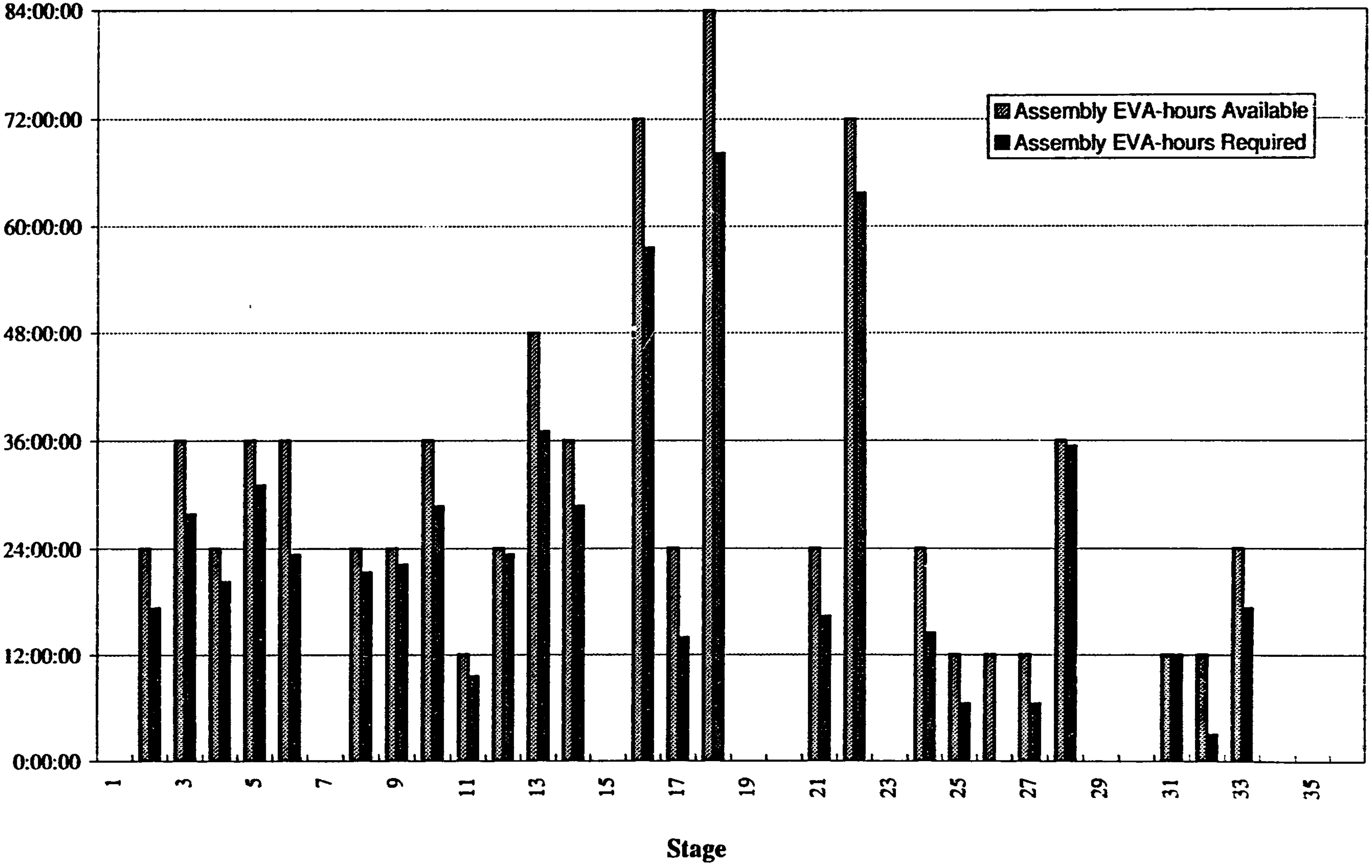


Figure 6.2-2 Comparison of Assembly EVA-Hours Available to the Assembly EVA-Hours Required

6.3 Reboost Propellant Trend Analysis

Space Station propellant requirements are governed by several factors including Station mass, ballistic number, propellant Isp, rendezvous altitude, reboost interval, and atmospheric parameters such as solar flux (F10.7), geomagnetic index (Ap), and atmospheric density. For this analysis, the STation Reboost Analysis Program (STRAP) Version 5.0 was utilized. STRAP is an analysis tool which provides the capability to quickly generate altitude profile data for the ISSA program. In this analysis, rendezvous altitudes were determined based on assembly requirements, and the upper altitudes were determined from the lower altitudes, the flight interval, and the orbital decay rate for the Station. All orbits were assumed to be circular and the reboost maneuver propellant was calculated using the ideal rocket equation assuming a Hohmann transfer. The Isp for the Aft and Zenith Bus was assumed to be constant at 295 seconds. Based on the location of the Bus and the Station configuration, thrust efficiencies were calculated and applied against the STRAP generated reboost maneuver propellant. This resulted in an increase of between zero and twenty-five percent in the reboost propellant with an average increase of five percent. In addition, five percent of the STRAP generated reboost requirement was added to account for pre- and post-docking procedures and another five percent was added to account for attitude control during reboost. These three additional propellant values were also added to the skip cycle requirements generated by the STRAP analysis. The objective of this analysis was not only to calculate Space Station propellant requirements, but also to determine the impact of varying atmospheric models and solar cycle start dates on the results. For this reason, six separate cases were evaluated corresponding to a mean and +2σ atmosphere for each of three solar cycle profiles. The results of these analyses are described below.

As shown in figures 6.3-1, 6.3-2, and 6.3-3 if the Station encounters a maximum, or +2σ atmosphere, it must reboost to a much higher upper altitude in order to decay back down to the next rendezvous altitude within the pre-determined flight interval. Therefore, the propellant requirements for the +2σ atmosphere cases are significantly higher than the corresponding mean atmosphere cases. Figures 6.3-4, 6.3-5, and 6.3-6 compare the orbital lifetime profiles for the mean and +2σ cases for each of the 3 solar cycle start dates. For any given Station altitude, the number of days of decay before the Station reaches a minimum altitude of 150 n.mi. is greater for the mean atmosphere case verses the +2σ atmosphere case. This is due to the fact that the solar flux and geomagnetic index values are higher in the +2σ atmosphere case and hence produce faster decay rates. Current ISSA operating plans dictate a minimum of 90 days to 150 n.mi. In several instances, the propellant analysis showed that the Station violates this minimum number, especially in the early years of the assembly sequence.

The difference in the solar cycle profiles also had a significant impact on the propellant analysis. The eleven year solar cycle is characterized in three STRAP input files, corresponding to an early, middle, and late start date for the next cycle. During the six years of the Station assembly sequence used in this analysis, each of the solar cycle profiles reaches its maximum point. For the early start solar cycle, the maximum solar flux occurs in August of 1999 and the middle and late cycle maximums occur at approximately one year increments beyond that (August 2000 and August 2001, respectively). The locations of these maximums impact the propellant analysis in several ways. With the early start solar cycle, the atmosphere is relatively harsh early on in the assembly sequence; however, it improves substantially in the outer years as the solar flux and geomagnetic index decrease. With the middle start solar cycle, the atmospheric conditions are more balanced over the Station build up, but the average solar flux over the assembly sequence is higher than either of the other two cases. On the other hand, the

late start solar cycle has the lowest average solar flux of the three profiles, but the harsher atmosphere in the later years produces significant deficits in propellant.

The start date of the solar cycle profile determines when the solar flux will reach its maximum value within the assembly sequence. Given a constant Station configuration, the propellant requirements would be higher early on with the early start cycle and correspondingly the lifetime to 150 n.mi. would be shorter and the required upper altitudes would be higher. These trends would also occur in the later years if a late start solar cycle were used. However, it is important to note that the Station configuration is far from constant during the assembly sequence and the continually changing mass and ballistic coefficients could greatly impact any trends observed solely within the atmospheric models.

Figures 6.3-7 through 6.3-12 show the propellant balance and distribution on Station during the assembly sequencefor each of the six reboost options that were anayzed. For each reboost date, the amount of propellant in each of the two Buses is shown as well as the amount of skip cycle propellant required at each rendezvous altitude. When the propellant balance is shown to be above the skip cycle line, this indicates that there is sufficient reserves to guarantee a 270 day skip cycle with a minimum lifetime of 90 days to 150 n.mi. If the Station altitude already ensures a 360 day lifetime to 150 n.mi, no skip cycle propellant is required. In several instances, the propellant balance shown in figures 6.3-7 through 6.3-12 indicates that the Station has run out of propellant and therefore another Bus must be launched sooner in the assembly sequence. For example, in the $+2\sigma$ atmosphere, early start solar cycle case (figure 6.3-7), the third Bus must be delivered before the fourth reboost of the year 2000. In the mean atmosphere, early start solar cycle case (figure 6.3-8) however, the highly positive balance indicates that the Bus delivery may be slipped further down into the assembly sequence. Further analysis would optimize the Bus delivery schedule so that an appropriate propellant balance is maintained on Station during the configuration buildup and throughout the operational phase.

For each of the six cases which were analyzed the ballistic coefficients, reboost propellant requirements, skip cycle propellant requirements, and orbital lifetimes have been provided for each stage of the build up sequence in tables 6.3-1 through 6.3-6.

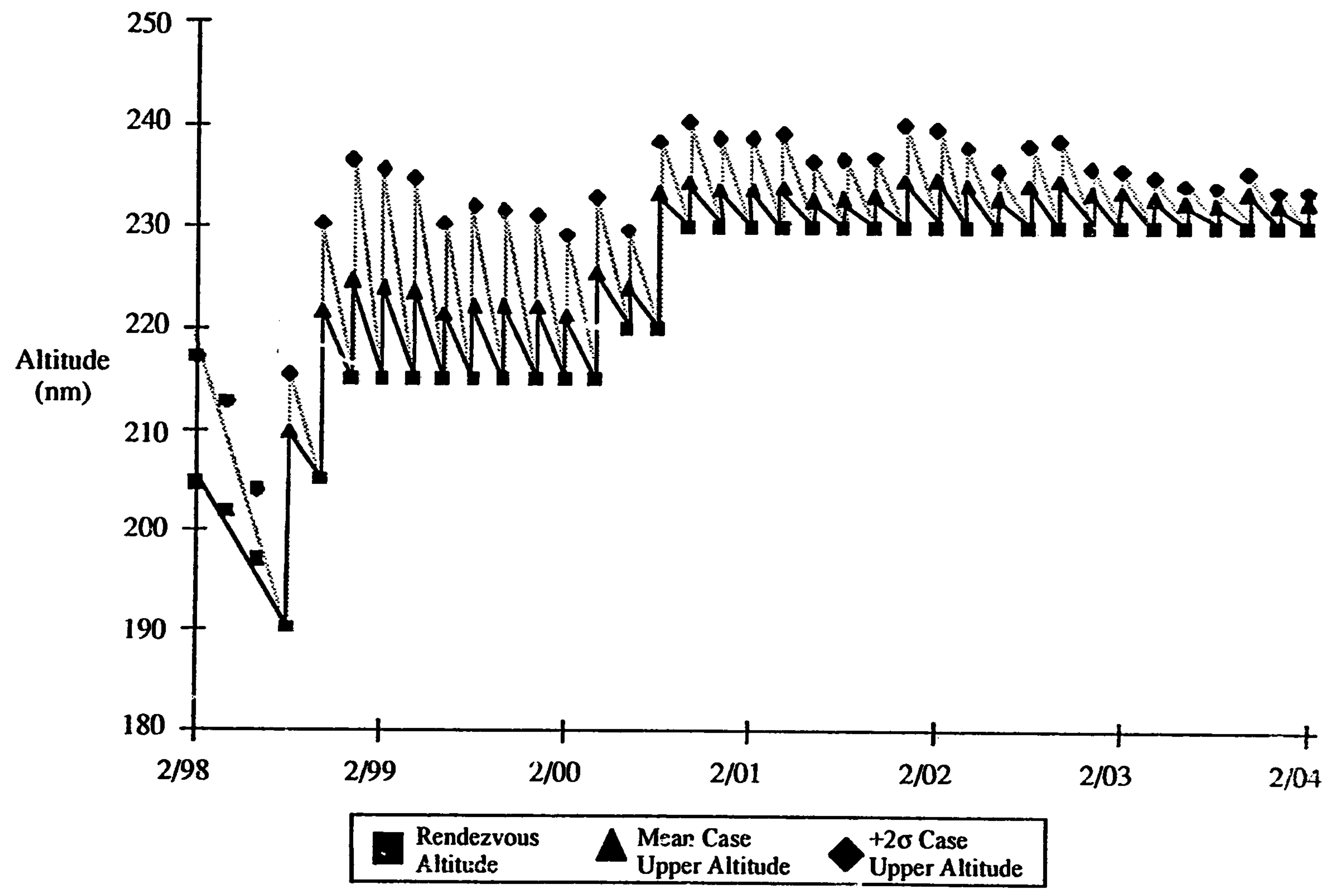


Figure 6.3-1 Altitude profiles for mean and +2σ with an early start of the solar cycle.

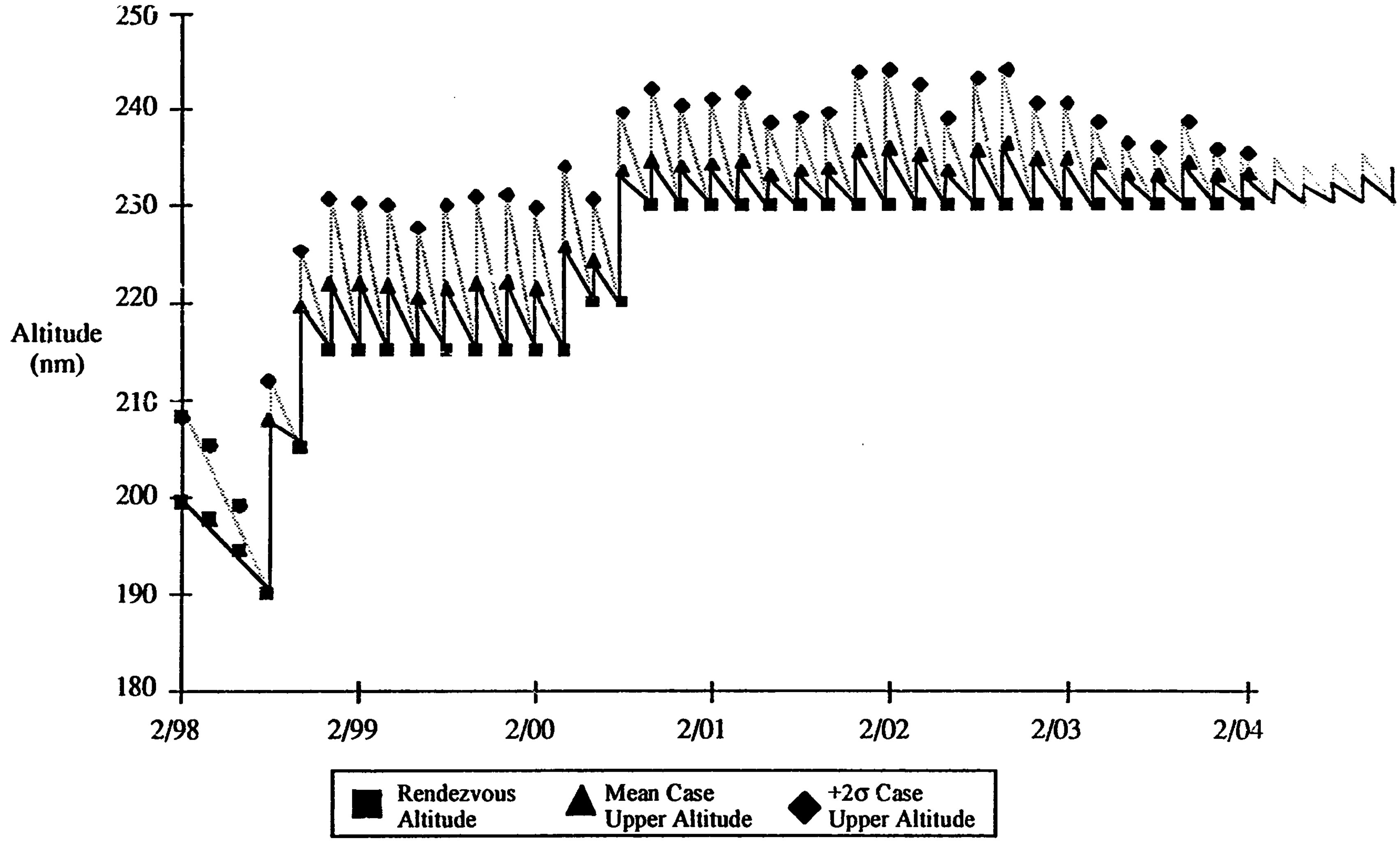


Figure 6.3-2 Altitude profiles for mean and +2σ with a nominal start of the solar cycle.

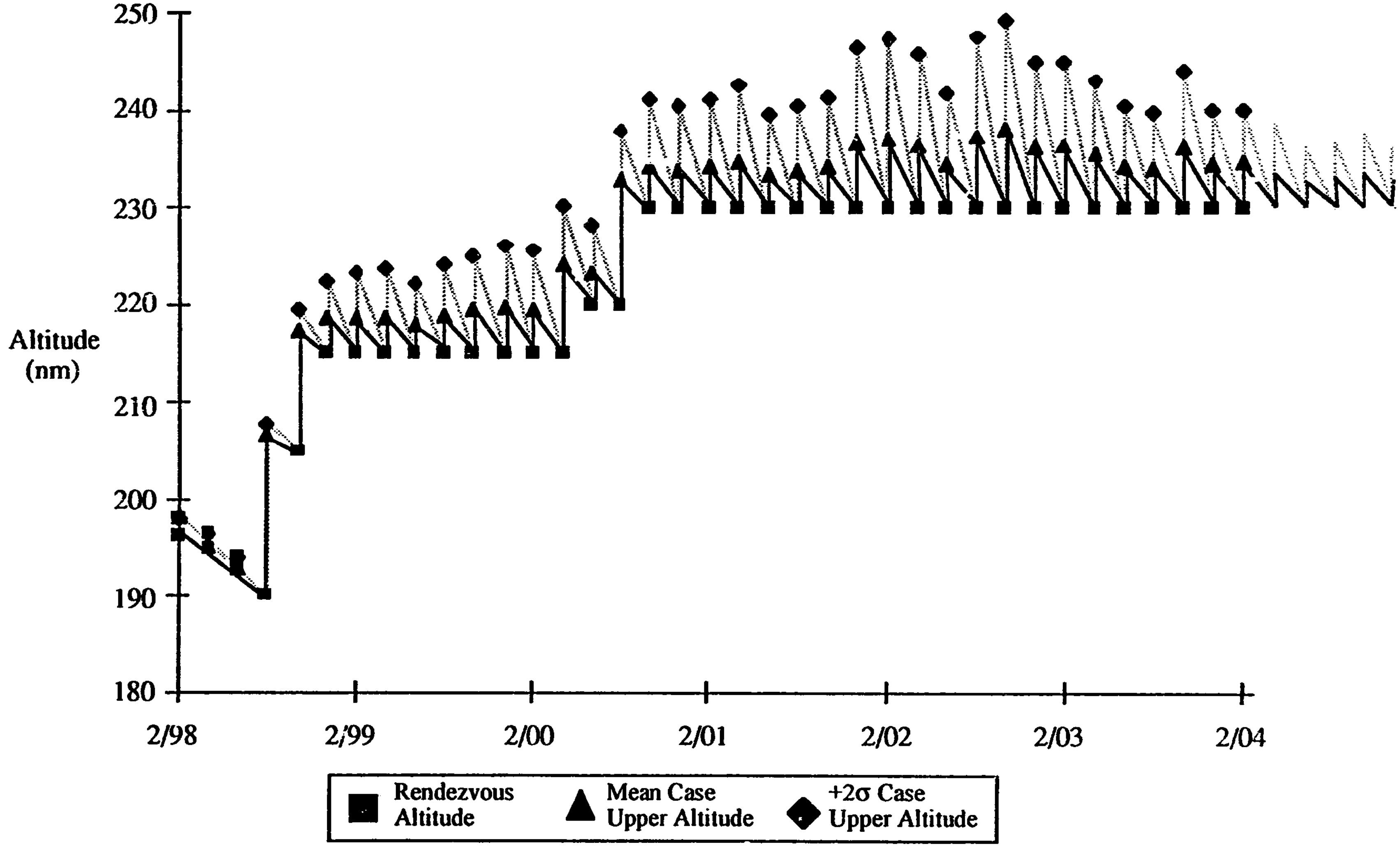


Figure 6.3-3 Altitude profiles for mean and +2σ with a late start of the solar cycle.

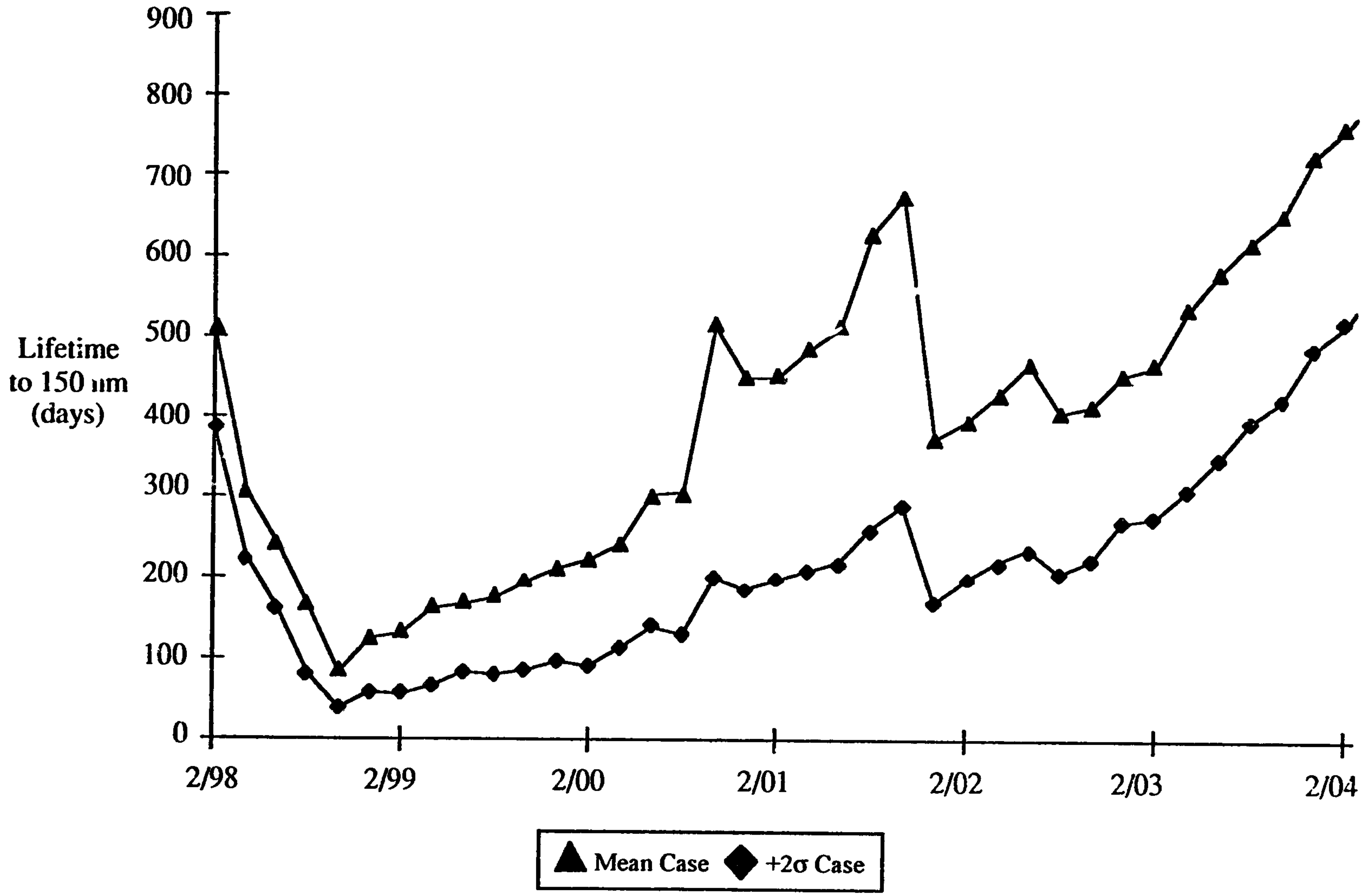


Figure 6.3-4 Lifetime profiles for mean and +2σ with an early start of the solar cycle.

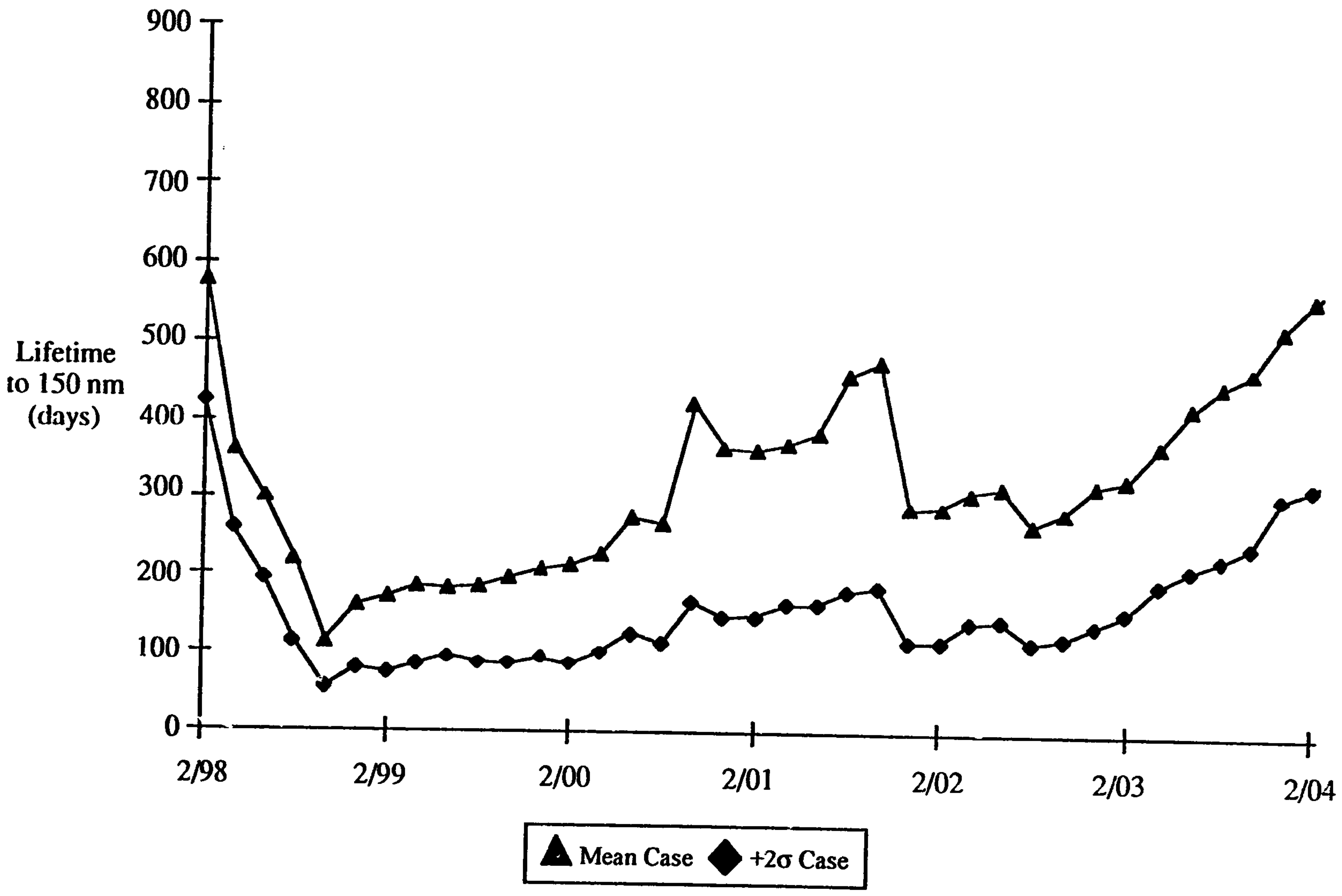


Figure 6.3-5 Lifetime profiles for mean and +2σ with a nominal start of the solar cycle.

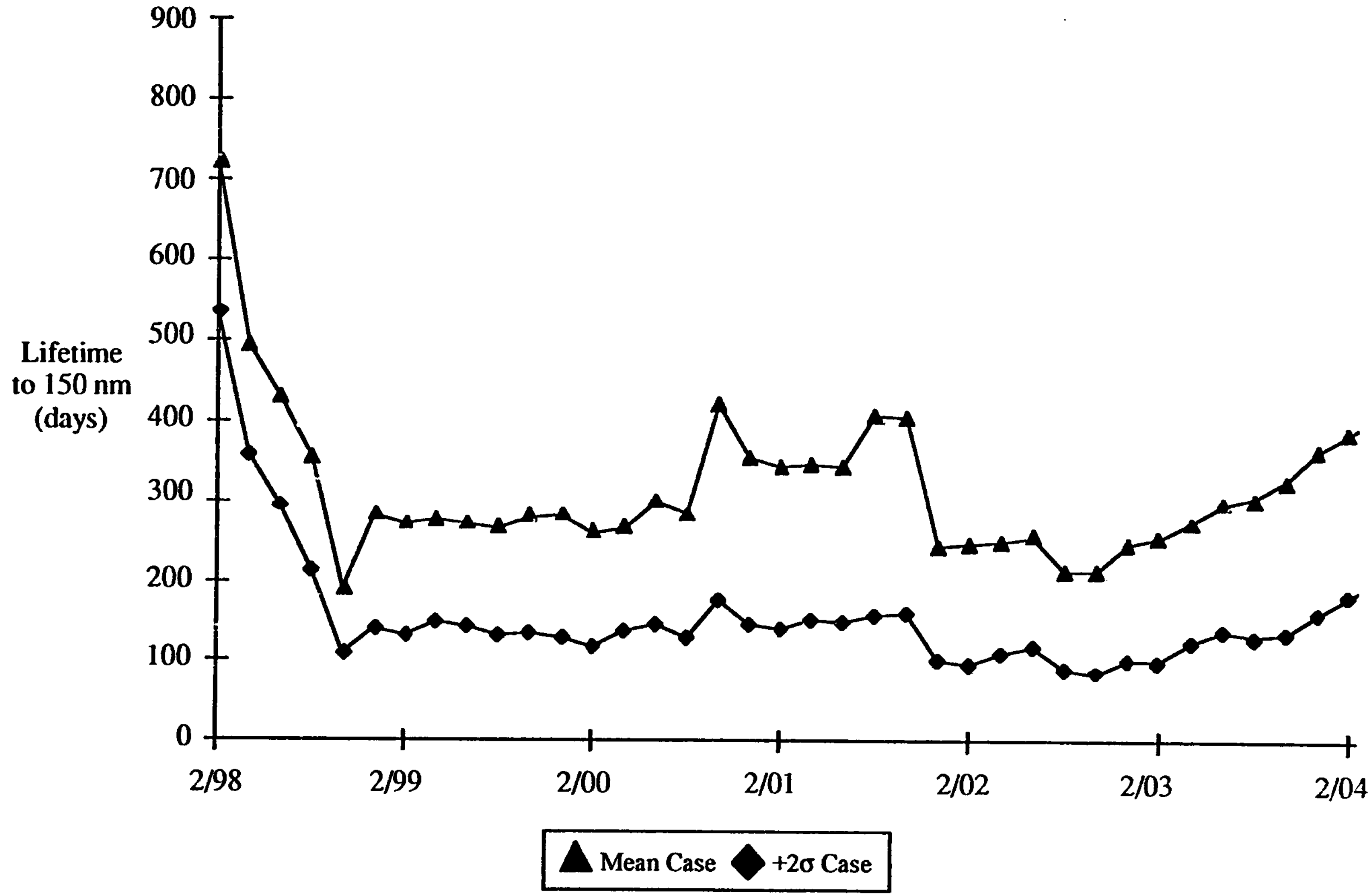


Figure 6.3-6 Lifetime profiles for mean and +2σ with a late start of the solar cycle.

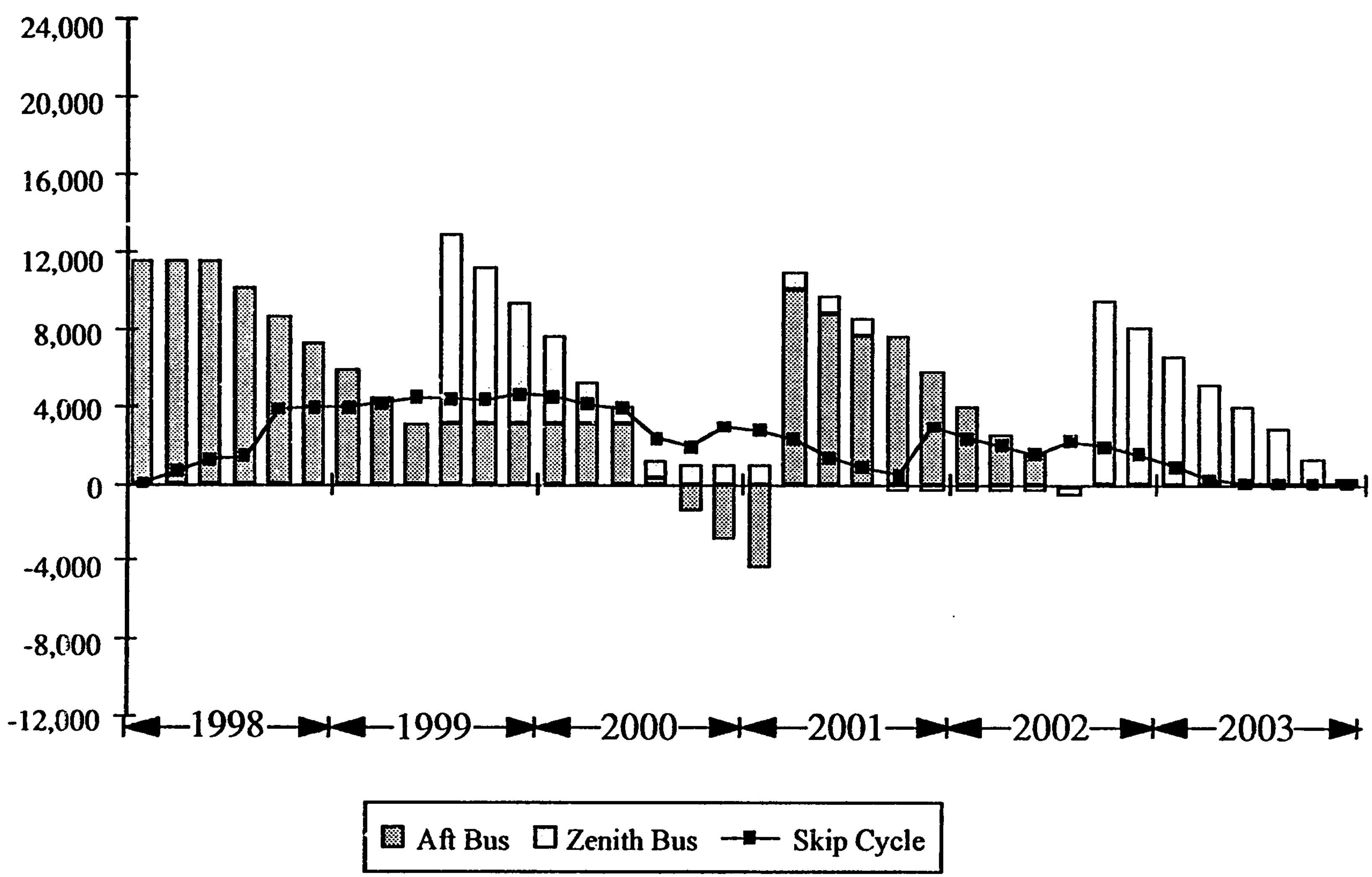


Figure 6.3-7 Propellant distribution for a +2σ atmosphere with an early start of the solar cycle.

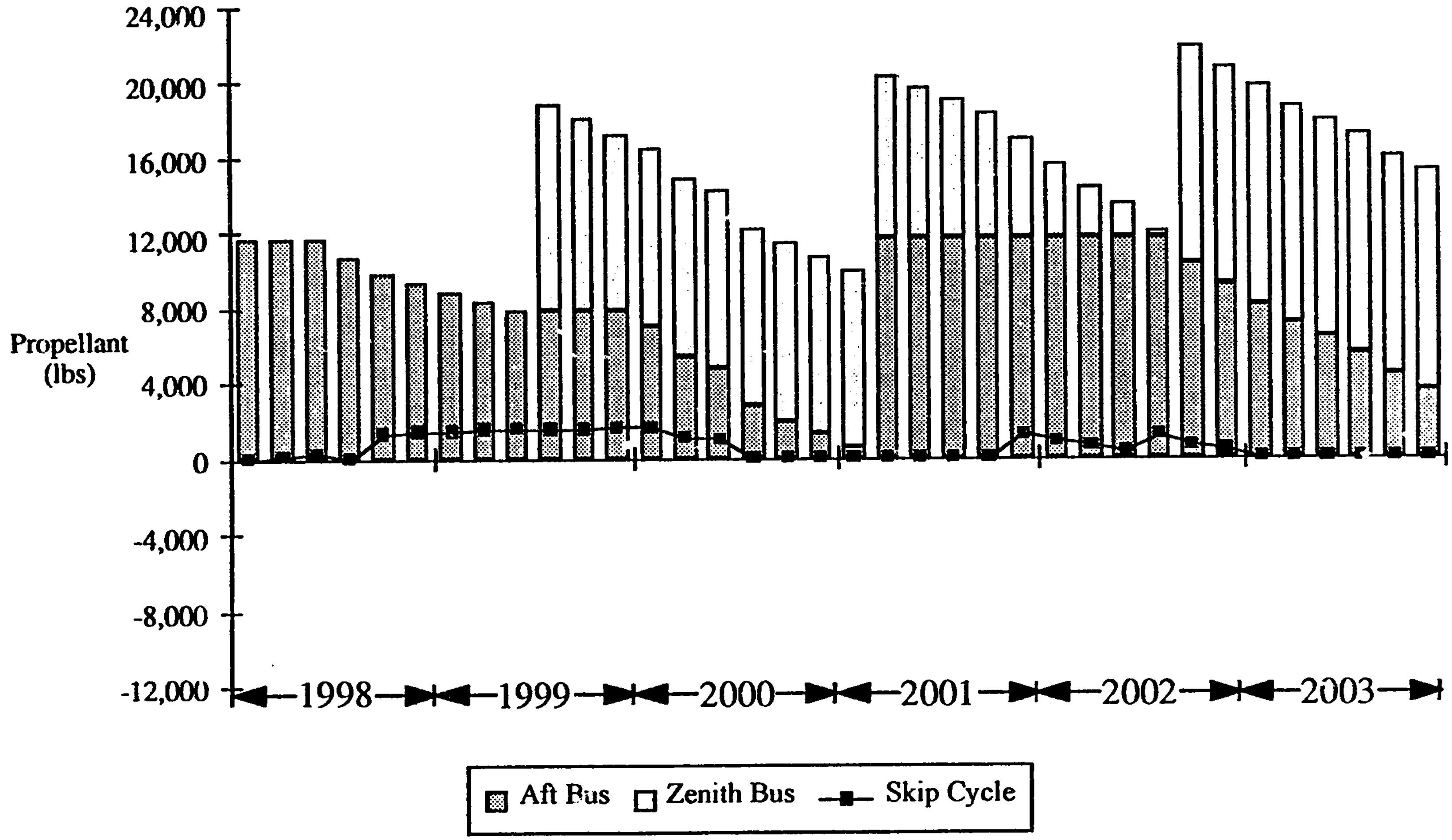


Figure 6.3-8 Propellant distribution for a mean atmosphere with an early start of the solar cycle.

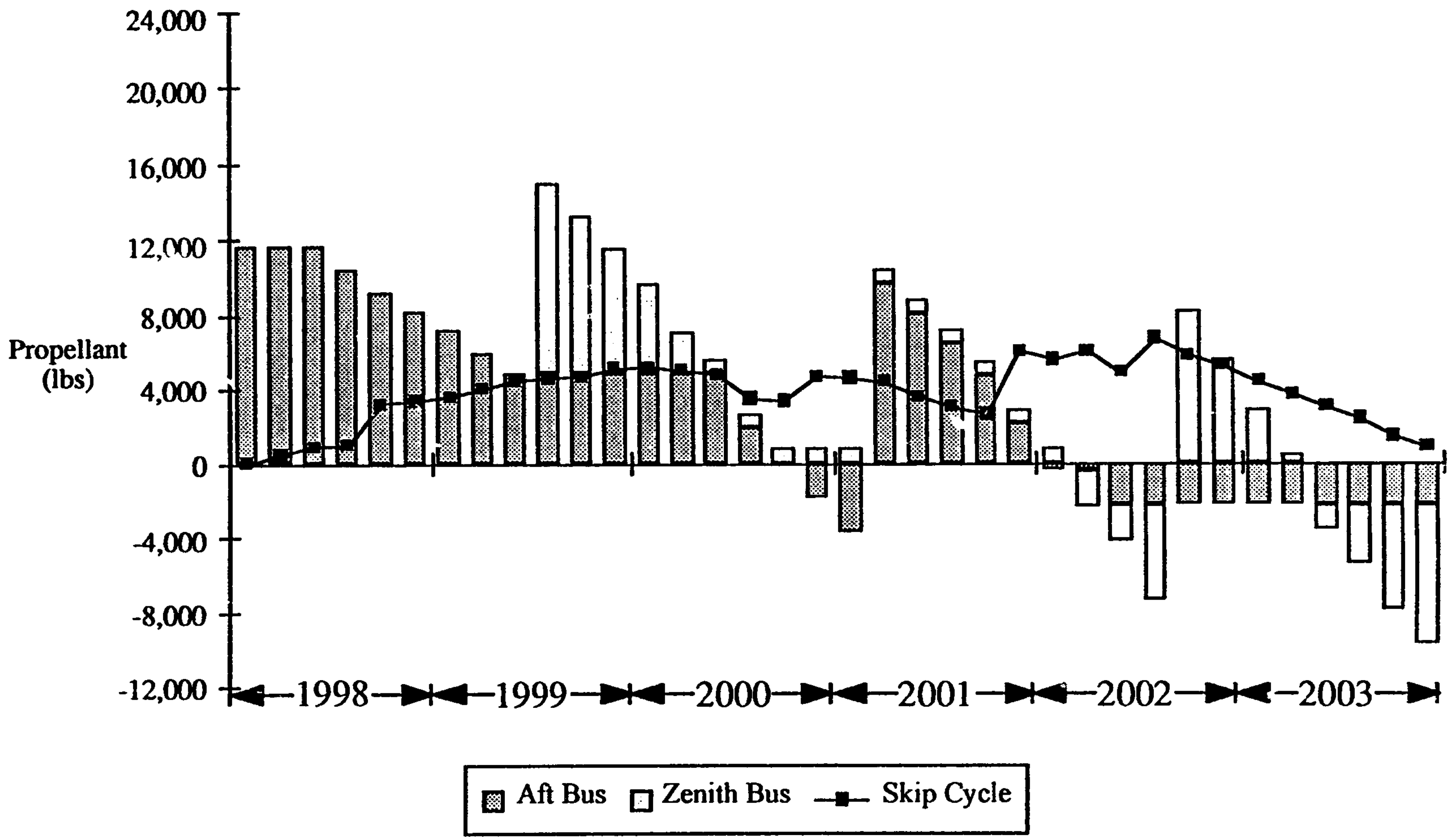


Figure 6.3-5 Propellant distribution for a +2σ atmosphere with a nominal start of the solar cycle.

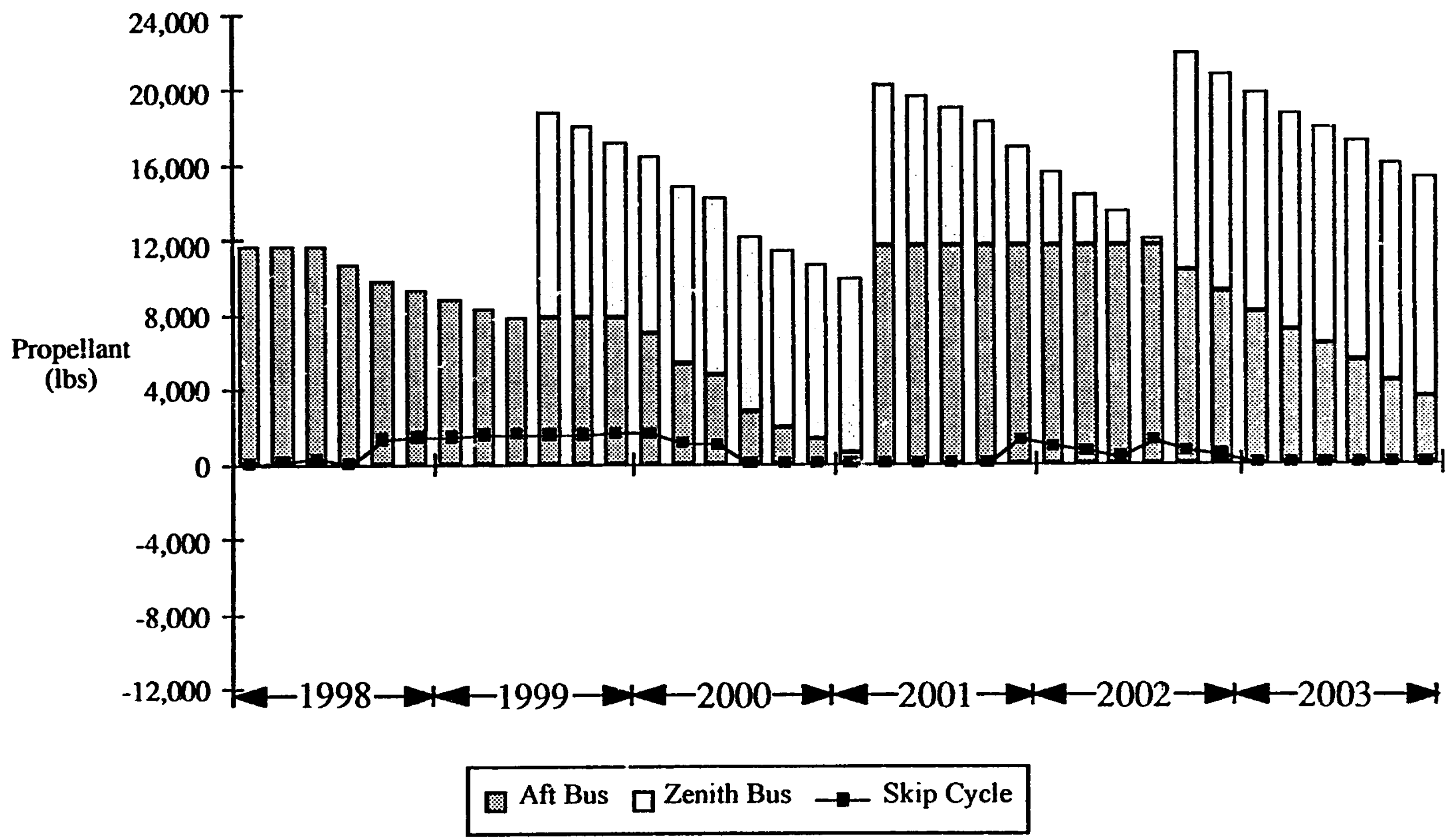


Figure 6.3-10 Propellant distribution for a mean atmosphere with a nominal start of the solar cycle.

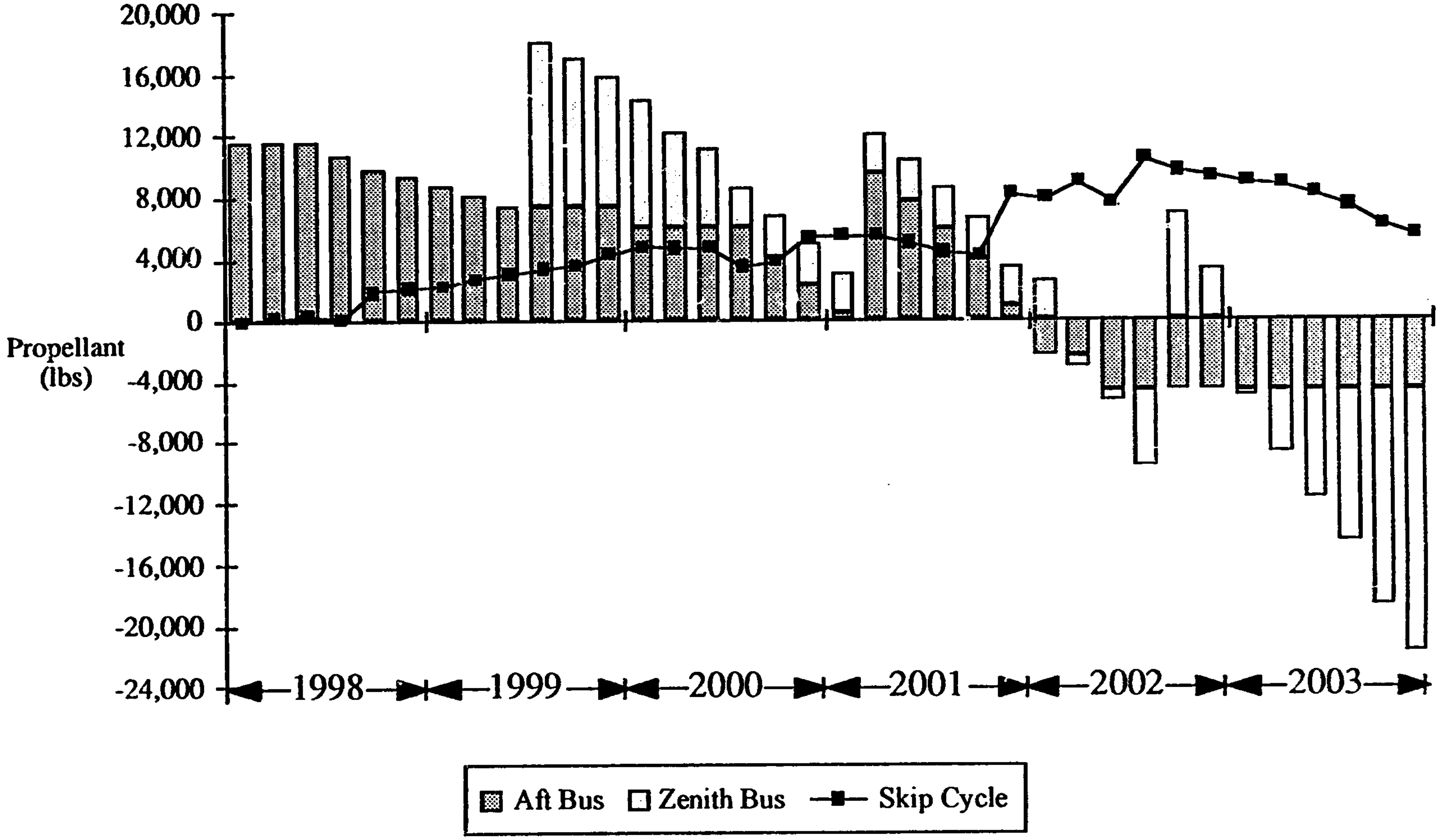


Figure 6.3-11 Propellant distribution for a +2σ atmosphere with a late start of the solar cycle.

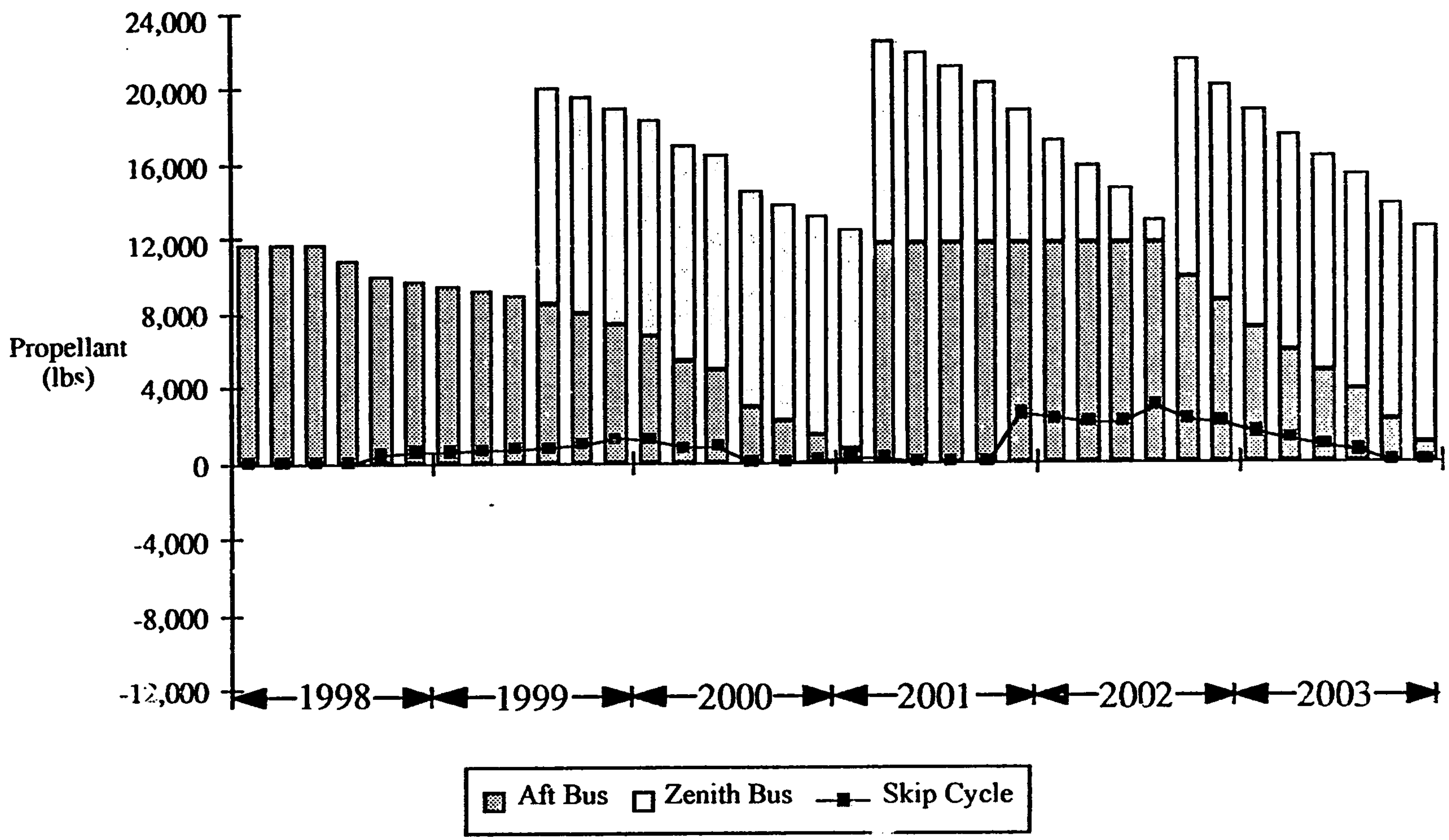


Figure 6.3-12 Propellant distribution for a mean atmosphere with a late start of the solar cycle.

Table 6.3-1 Propellant Requirements for a +2σ Atmosphere - Early Solar Cycle Start

Tier 2 Propellant Req'ts - +2 Sigma Atm. Case - Early Start									Reboost Propellant							Prop Balance After Reboost			Skip Cycle		Skip Cycle
#	Launch Date	Flight Name	Lower Alt. (nm)	Upper Alt. (nm)	Stage Mass (lbs)	Ballistic # (lbs/ft^2)	Lifetime (Days)	F10.7	Reboost Date	AR Bus	Zen. Bus	AR Bus Eff.	Zen. Bus Eff.	Strap* Output	Reboost Prop**	AR Bus***	Zen. Bus***	Total Prop Available	Strap* SC Prop (lbs)	Total SC Prop** (lbs)	Prop Margin
1	2/1/98	1A	217.2	217.2	31,265	56.52	336	196.9	2/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	38	42	11,558
2	4/1/98	2A	212.9	212.9	59,842	38.89	223	204.2	4/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	571	629	10,972
3	6/1/98	3A	203.9	203.9	82,893	42.83	180	214.8	6/12/98	x		100.0%	N/A	0	0	11,600	0	11,600	1,129	1,242	10,358
4	8/1/98	4A	190	218	115,301	37.89	80	226.9	8/11/98	x		86.7%	N/A	1,071	1,342	10,258	0	10,258	1,108	1,386	8,871
5	11/1/98	5A	205	230	145,083	10.00	38	231.7	11/12/98	x		96.5%	N/A	1,328	1,509	8,749	0	8,749	3,402	3,866	4,883
6	12/1/98	6A	215	236	158,070	10.84	59	233.7	12/15/98	x		98.5%	N/A	1,220	1,361	7,388	0	7,388	3,547	3,955	3,433
7	2/1/99	UF-1	215	236	173,282	12.01	57	238.8	2/15/99	x		100.0%	N/A	1,288	1,416	5,972	0	5,972	3,595	3,954	2,018
8	4/1/99	7A	215	235	194,666	12.87	65	245.2	4/12/99	x		100.0%	N/A	1,383	1,521	4,451	0	4,451	3,815	4,196	254
9	6/1/99	8A	215	230	224,860	14.43	63	243.3	6/10/99	x		100.0%	N/A	1,247	1,372	3,079	0	3,079	4,058	4,484	-1,385
10	8/1/99	BF-2	215	232	253,529	16.35	83	245.7	8/10/99		x	87.9%	100.0%	1,548	1,733	3,079	9,597	12,675	4,040	4,444	8,232
11	10/1/99	UF-2	215	232	282,347	16.62	65	239.4	10/15/99		x	88.5%	100.0%	1,563	1,719	3,079	8,178	11,257	3,997	4,396	6,861
12	12/1/99	9A	215	231	282,189	16.56	87	232.8	12/10/99		x	89.0%	100.0%	1,639	1,803	3,079	6,378	9,455	4,225	4,648	4,807
13	2/1/00	10A	215	229	308,844	17.98	82	233.1	2/15/00		x	82.3%	100.0%	1,585	1,743	3,079	4,633	7,712	4,123	4,536	3,178
14	4/1/00	11A	215	233	339,508	18.01	114	229.1	4/12/00		x	82.3%	100.0%	2,193	2,412	3,079	2,220	5,298	3,789	4,148	1,153
15	6/1/00	UF-3	220	230	339,508	18.50	140	227.6	6/15/00		x	82.2%	100.0%	1,183	1,301	3,079	920	3,998	3,587	3,923	75
16	8/1/00	1 J/A	220	238	357,145	18.47	131	225.6	8/13/00	x		93.1%	100.0%	2,371	2,784	295	920	1,214	2,014	2,365	-1,150
17	10/1/00	12A	230	240	380,214	20.28	201	218.6	10/11/00	x		93.8%	100.0%	1,468	1,709	-1,414	920	-495	1,633	1,905	-2,398
18	12/1/00	12Ap	230	239	386,828	16.17	185	212.0	12/18/00	x		93.6%	100.0%	1,253	1,464	-2,878	920	-1,959	2,543	2,671	-4,630
19	2/1/01	UF-4p	230	239	386,828	15.88	197	204.0	2/15/01	x		93.4%	100.0%	1,270	1,486	-4,365	920	-3,445	2,327	2,724	-6,169
20	4/1/01	BF-3	233	233	386,828	15.86	206	200.4	4/10/01	x		93.4%	100.0%	1,318	1,542	10,058	920	10,977	1,999	2,340	8,637
21	6/1/01	13A	230	237	434,308	18.57	218	195.7	6/12/01	x		93.5%	100.0%	1,017	1,189	8,869	920	9,789	1,150	1,345	8,443
22	8/1/01	13Ap	230	237	434,308	10.08	200	191.5	8/18/01	x		100.0%	91.7%	1,046	1,150	7,718	920	8,638	775	852	7,785
23	10/2/01	UF-5p	230	237	434,308	10.08	290	182.8	10/18/01		x	100.0%	91.7%	1,079	1,285	7,718	-365	7,353	354	421	6,932
24	12/1/01	1J	230	240	487,375	10.74	189	178.3	12/10/01	x		100.0%	90.2%	1,690	1,859	5,859	-365	5,494	2,734	3,007	2,487
25	2/1/02	2E	230	240	489,580	10.82	197	171.1	2/12/02	x		100.0%	94.2%	1,629	1,792	4,068	-365	3,702	2,149	2,364	1,338
26	4/1/02	UF-6p	230	238	489,580	10.82	218	158.1	4/15/02	x		100.0%	94.2%	1,348	1,483	2,585	-365	2,218	1,785	1,941	278
27	6/1/02	2J/A	230	238	498,240	11.28	235	152.7	6/15/02	x		100.0%	76.7%	1,006	1,107	1,478	-365	1,112	1,410	1,551	-439
28	8/1/02	15A	230	238	529,104	9.45	208	148.1	8/12/02	x		100.0%	86.0%	1,553	1,709	-231	-365	-596	2,028	2,229	-2,825
29	10/1/02	BF-4	233	239	529,104	9.45	223	141.1	10/15/02		x	100.0%	85.0%	1,830	2,659	-231	9,542	9,311	1,604	1,989	7,412
30	12/1/02	UF-7p	230	238	529,104	9.43	270	132.4	12/15/02		x	100.0%	86.2%	1,134	1,428	-231	8,113	7,882	1,227	1,548	6,338
31	2/1/03	14A	230	238	551,150	9.86	275	119.5	2/12/03		x	100.0%	83.7%	1,128	1,458	-231	6,655	6,424	714	825	5,500
32	4/1/03	1E	230	235	580,424	10.28	308	118.7	4/12/03		x	100.0%	80.9%	1,073	1,434	-2[illegible]	5,222	4,991	178	235	4,755
33	6/1/03	16A	230	234	612,879	10.72	346	119.8	6/9/03		x	100.0%	83.2%	911	1,186	-231	4,036	3,805	0	0	3,805
34	8/1/03	17A	230	234	621,697	10.88	394	117.7	8/11/03		x	100.0%	83.8%	861	1,114	-231	2,923	2,692	0	0	2,692
35	10/2/03	18A	230	238	645,948	11.05	420	114.6	10/4/03		x	100.0%	85.6%	1,282	1,626	-231	1,297	1,066	0	0	1,066
36	12/1/03	19A	230	234	650,357	11.11	485	105.4	12/10/03		x	100.0%	85.2%	826	1,052	-231	245	14	0	0	14

* STRAP version 5.0

Tier 2, masses and ballistic numbers from LaRC 3/95

ER Atm; "A" Altitude Strategy

BN Option = WORST_CASE

Skip-Cycle Calculations = TRUE

Skip-Cycle Interval = 270

SC Min. Alt. Strategy = L

SC Min. Alt. Lifetime = 90

SC Min. Alt. Lifetime Altitude = 150

Semi-Annual Effect = TRUE

Geomagnetic Correction = TRUE

Solar Flux Source = TABLES

ATMOSPHERE MODEL = +2_SIGMA

FLUX DATA FILE = data_files/ER-SSP30425.DAT

AP DATA FILE = data_files/ER-SSP30425-AP.DAT

** Propellant numbers take into account efficiency of Bus being used and include 5% for Pre- and Post- docking maneuvers and 5% for attitude control during reboost

*** Bus ISP = 285 sec; each Bus is delivered with 11,600 lbs of usable propellant

Table 6.3-2 Propellant Requirements for a Mean Atmosphere - Early Solar Cycle Start

Tier 2 Propellant Req's - Mean Atm. Case - Early Start									Reboost Propellant							Prop Balance After Reboost			Skip Cycle		Skip Cycle Prop Margin
#	Launch Date	Flight Name	Lower Alt. (nm)	Upper Alt. (nm)	Stage Mass (lbs)	Ballistic # (lbs/ft^2)	Lifetime (Days)	F10.7	Reboost Date	Alt Bus	Zen. Bus	Alt Bus Eff.	Zen. Bus Eff.	Strap* Output	Reboost Prop**	Alt Bus***	Zen Bus***	Total Prop Available	Strap* SC Prop (lbs)	Total SC Prop** (lbs)	
1	2/1/98	1A	204.6	204.6	31,365	56.52	508	124.3	2/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	0	0	11,600
2	4/1/98	2A	201.9	201.9	58,642	38.89	305	128.6	4/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	228	249	11,351
3	6/1/98	3A	198.9	198.9	82,893	42.83	242	133.3	6/12/98	x		100.0%	N/A	0	0	11,600	0	11,600	442	486	11,114
4	8/1/98	4A	190	210	115,301	27.89	165	139.6	9/11/98	x		88.7%	N/A	828	1,035	10,565	0	10,565	114	143	10,422
5	11/1/98	5A	205	222	145,063	10.00	84	143.2	11/12/98	x		98.5%	N/A	881	1,001	9,563	0	9,563	1,543	1,753	7,810
6	12/1/98	6A	215	225	158,075	10.84	124	144.6	12/15/98	x		98.5%	N/A	552	615	8,948	0	8,948	1,557	1,737	7,211
7	2/1/99	UF-1	215	224	173,282	12.01	131	148.7	2/15/99	x		100.0%	N/A	573	630	8,318	0	8,318	1,500	1,850	6,468
8	4/1/99	7A	215	224	194,686	12.87	162	147.7	4/12/99	x		100.0%	N/A	607	667	7,651	0	7,651	1,533	1,882	5,769
9	6/1/99	8A	215	222	224,869	14.43	187	148.4	6/10/99	x		100.0%	N/A	531	585	7,066	0	7,066	1,524	1,877	5,189
10	8/1/99	BF-2	215	222	253,529	16.35	176	148.2	8/10/99		x	87.9%	100.0%	872	739	7,065	10,861	17,927	1,349	1,484	16,443
11	10/1/99	UF-2	215	222	262,347	16.82	194	145.7	10/15/99		x	88.5%	100.0%	703	773	7,066	10,088	17,154	1,290	1,419	15,735
12	12/1/99	9A	215	222	282,189	16.56	212	144.9	12/10/99		x	89.0%	100.0%	735	809	7,066	9,279	16,345	1,357	1,483	14,862
13	2/1/00	10A	215	221	308,644	17.99	222	144.7	2/15/00		x	92.3%	100.0%	712	783	7,066	8,497	15,563	1,144	1,258	14,304
14	4/1/00	11A	215	228	339,508	18.01	242	143.5	4/12/00	x		92.3%	100.0%	1,298	1,537	5,529	8,497	14,026	581	664	13,362
15	6/1/00	UF-3	220	224	339,508	18.50	301	142.3	6/15/00	x		92.2%	100.0%	494	586	4,944	8,497	13,440	432	512	12,928
16	8/1/00	1 J/A	220	233	357,145	19.47	304	141.3	8/13/00	x		93.1%	100.0%	1,715	2,014	2,930	8,497	11,427	0	0	11,427
17	10/1/00	12A	230	234	380,214	20.28	513	138.4	10/11/00	x		93.8%	100.0%	605	708	2,224	8,497	10,721	0	0	10,721
18	12/1/00	12Ap	230	234	396,828	16.17	449	135.5	12/18/00	x		93.6%	100.0%	519	607	1,618	8,497	10,114	0	0	10,114
19	2/1/01	UF-4p	230	234	396,828	15.88	450	133.0	2/15/01	x		93.4%	100.0%	530	620	997	8,497	9,494	0	0	9,494
20	4/1/01	BF-3	230	234	396,828	15.88	493	129.8	4/10/01		x	93.4%	100.0%	551	638	11,600	7,830	19,430	0	0	19,430
21	6/1/01	13A	230	233	434,308	18.57	511	127.3	6/12/01		x	93.5%	100.0%	414	455	11,600	7,435	19,035	0	0	19,035
22	8/1/01	13Ap	230	233	434,308	10.08	627	125.1	8/18/01		x	100.0%	91.7%	445	529	11,600	6,906	18,506	0	0	18,506
23	10/2/01	UF-5p	230	233	434,308	10.08	673	122.3	10/16/01		x	100.0%	91.7%	484	577	11,600	6,329	17,929	0	0	17,929
24	12/1/01	1J	230	235	487,375	10.74	372	120.5	12/10/01		x	100.0%	80.2%	782	1,053	11,600	5,278	16,878	0	0	16,878
25	2/1/02	2E	230	235	469,580	10.82	394	117.9	2/12/02		x	100.0%	84.2%	798	1,027	11,600	4,249	15,849	0	0	15,849
26	4/1/02	UF-6p	230	234	469,580	10.82	427	114.8	4/15/02		x	100.0%	84.2%	688	885	11,600	3,383	14,983	0	0	14,983
27	6/1/02	2J/A	230	233	498,240	11.29	485	111.1	6/15/02		x	100.0%	78.7%	498	701	11,600	2,662	14,262	0	0	14,262
28	8/1/02	15A	230	234	529,104	9.45	403	108.0	8/12/02		x	100.0%	88.0%	798	1,005	11,600	1,657	13,257	0	0	13,257
29	10/1/02	EF-4	230	235	529,104	9.45	414	104.9	10/15/02	x		100.0%	89.9%	972	659	10,941	11,600	22,241	0	0	22,241
30	12/1/02	UF-7p	230	233	529,104	9.43	451	101.9	12/15/02	x		100.0%	80.2%	847	712	9,929	11,600	21,529	0	0	21,529
31	2/1/03	14A	230	233	551,150	9.86	484	98.9	2/12/03	x		100.0%	83.7%	689	758	9,171	11,600	20,771	0	0	20,771
32	4/1/03	1E	230	233	588,424	10.29	533	96.6	4/12/03	x		100.0%	80.9%	628	691	8,490	11,600	20,080	0	0	20,080
33	6/1/03	16A	230	232	612,878	10.72	580	94.8	6/8/03	x		100.0%	83.2%	517	589	7,911	11,600	19,511	0	0	19,511
34	8/1/03	17A	230	232	621,697	10.88	617	92.8	8/11/03	x		100.0%	83.8%	493	542	7,369	11,600	18,969	0	0	18,969
35	10/2/03	18A	230	233	645,948	11.05	652	90.6	10/4/03	x		100.0%	85.6%	778	854	8,515	11,600	18,115	0	0	18,115
36	12/1/03	19A	230	232	650,357	11.11	728	88.4	12/10/03	x		100.0%	85.2%	543	597	5,918	11,600	17,518	0	0	17,518

* STRAP version 3.0

Tier 2, masses and ballistic numbers from LaRC 3/95
ER Atm; "A" Altitude Strategy
BN Option = WORST_CASE
Skip-Cycle Calculations = TRUE
Skip-Cycle Interval = 270
SC Min. Alt. Strategy = L
SC Min. Alt. Lifetime = 90
SC Min. Alt. Lifetime Altitude = 150
Semi-Annual Effect = TRUE
Geomagnetic Correction = TRUE
Solar Flux Source = TABLES
ATMOSPHERE MODEL = MEAN
FLUX DATA FILE = data_files/ER-SSP30425.DAT
AP DATA FILE = data_files/ER-SSP30425-AP.DAT

** Propellant numbers take into account efficiency of Bus being used and include 5% for Pre- and Post- docking maneuvers and 5% for attitude control during reboost

*** Bus ISP = 295 sec; each Bus is delivered with 11,600 lbs of usable propellant

Table 6.3-3 Propellant Requirements for a +2σ Atmosphere - Nominal Solar Cycle Start

Tier 2 Propellant Req'ts - +2 Sigma Atm. Case - Nominal Start												Reboost Propellant					Prop Balance After Reboost			Skip Cycle		Skip Cycle Prop Margin
#	Launch Date	Flight Name	Lower Alt. (nm)	Upper Alt. (nm)	Stage Mass (lbs)	Ballistic # (lbs/ft**2)	Lifetime (Days)	F10.7	Reboost Date	Alt Bus	Zen. Bus	Alt Bus Eff.	Zen. Bus Eff.	Strap* Output	Reboost Prop**	Alt Bus***	Zen. Bus***	Total Prop Available	Strap* SC Prop (lbs)	Total SC Prop** (lbs)	
1	2/1/98	1A	203.3	203.3	31,365	56.52	422	137.8	3/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	0	0	11,600
2	4/1/98	2A	205.2	205.2	58,642	36.89	258	147.6	4/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	421	463	11,137
3	6/1/98	3A	198.0	198.0	82,893	42.83	195	155.7	6/12/98	x		100.0%	N/A	0	0	11,600	0	11,600	835	919	10,981
4	8/1/98	4A	190	212	115,301	37.89	115	169.1	8/11/98	x		86.7%	N/A	913	1,144	10,456	0	10,456	785	859	9,497
5	11/1/98	5A	205	225	145,083	10.00	54	177.1	11/12/98	x		98.5%	N/A	1,069	1,215	9,241	0	9,241	2,944	3,232	6,009
6	12/1/98	6A	215	231	158,070	10.84	80	188.1	12/15/98	x		98.5%	N/A	894	997	8,244	0	8,244	3,094	3,451	4,794
7	2/1/99	UF-1	215	230	173,282	12.01	75	194.3	2/15/99	x		100.0%	N/A	957	1,053	7,191	0	7,191	3,281	3,609	3,583
8	4/1/99	7A	215	230	194,686	12.87	88	199.6	4/12/99	x		100.0%	N/A	1,065	1,172	6,019	0	6,019	3,672	4,039	1,980
9	6/1/99	8A	215	228	224,869	14.43	97	210.6	6/10/99	x		100.0%	N/A	1,031	1,134	4,886	0	4,886	4,053	4,459	427
10	8/1/99	BF-2	215	230	253,529	16.35	89	217.2	8/10/99		x	87.9%	100.0%	1,374	1,511	4,665	10,089	14,674	4,212	4,633	10,341
11	10/1/99	UF-2	215	231	262,347	18.62	88	226.9	10/15/99		x	88.5%	100.0%	1,514	1,686	4,886	8,423	13,308	4,310	4,741	8,567
12	12/1/99	9A	215	231	282,189	18.56	98	231.7	12/10/99		x	89.0%	100.0%	1,643	1,807	4,886	6,618	11,501	4,697	5,167	6,334
13	2/1/00	10A	215	230	308,644	17.99	87	235.6	2/15/00		x	92.3%	100.0%	1,647	1,811	4,886	4,804	9,690	4,749	5,220	4,470
14	4/1/00	11A	215	234	338,508	18.01	103	242.8	4/12/00		x	92.3%	100.0%	2,353	2,588	4,886	2,218	7,102	4,582	5,013	2,084
15	6/1/00	UF-3	220	231	339,508	18.50	128	244.5	6/15/00		x	92.2%	100.0%	1,309	1,440	4,886	778	5,662	4,448	4,892	770
16	8/1/00	1J/A	220	240	357,145	18.47	114	244.7	8/13/00	x		93.1%	100.0%	2,535	2,976	1,910	778	2,688	3,031	3,559	-873
17	10/1/00	12A	230	242	390,214	20.29	169	243.3	10/11/00	x		93.8%	100.0%	1,721	2,007	-97	776	680	2,887	3,367	-2,687
18	12/1/00	12Ap	230	241	396,828	16.17	149	235.0	12/18/00	x		93.6%	100.0%	1,516	1,771	-1,868	776	-1,092	4,030	4,708	-5,800
19	2/1/01	UF-4p	230	241	396,828	15.88	150	233.3	2/15/01	x		93.4%	100.0%	1,583	1,853	-3,721	778	-2,945	3,919	4,588	-7,533
20	4/1/01	BF-3	230	242	396,926	15.88	166	231.2	4/10/01	x		93.4%	100.0%	1,692	1,959	5,631	776	13,459	3,740	4,378	6,030
21	6/1/01	13A	230	239	434,306	18.57	164	228.1	6/12/01	x		93.5%	100.0%	1,339	1,568	8,065	778	8,842	3,109	3,636	5,206
22	8/1/01	13Ap	230	239	434,306	10.08	183	226.7	8/18/01	x		100.0%	91.7%	1,452	1,597	6,468	778	7,245	2,806	3,387	4,158
23	10/2/01	UF-5p	230	240	434,306	10.08	188	223.0	10/18/01	x		100.0%	91.7%	1,528	1,680	4,788	778	5,564	2,451	2,697	2,868
24	12/1/01	1J	230	244	467,375	10.74	118	215.2	12/10/01	x		100.0%	90.2%	2,382	2,599	2,189	778	2,968	5,539	6,093	-3,125
25	2/1/02	2E	230	244	480,580	10.82	119	208.9	2/12/02	x		100.0%	84.2%	2,391	2,630	-441	778	335	5,107	5,613	-5,282
26	4/1/02	UF-6p	230	243	480,580	10.82	143	203.6	4/15/02		x	100.0%	84.2%	2,138	2,753	-441	-1,977	-2,418	4,723	6,081	-8,499
27	6/1/02	2J/A	230	238	498,240	11.29	148	198.8	6/15/02	x		100.0%	76.7%	1,632	1,795	-2,236	-1,977	-4,213	4,487	4,935	-9,149
28	8/1/02	15A	230	243	529,104	9.45	117	184.8	8/12/02		x	100.0%	86.0%	2,528	3,193	-2,236	-5,169	-7,406	5,333	6,735	-14,140
29	10/1/02	BF-4	230	244	529,104	9.45	124	187.4	10/15/02		x	100.0%	89.9%	2,695	3,397	-2,236	8,213	5,976	4,639	5,955	117
30	12/1/02	UF-7p	230	241	529,104	9.43	140	178.6	12/15/02		x	100.0%	88.2%	2,034	2,563	-2,236	5,650	3,414	4,180	5,267	-1,854
31	2/1/03	14A	230	241	551,150	9.88	156	174.9	2/12/03		x	100.0%	83.7%	2,114	2,737	-2,236	2,913	676	3,392	4,392	-3,718
32	4/1/03	1E	230	239	586,424	10.29	193	164.5	4/12/03		x	100.0%	80.9%	1,809	2,418	-2,236	495	-1,742	2,803	3,748	-5,487
33	6/1/03	16A	230	237	612,879	10.72	211	154.4	6/9/03		x	100.0%	83.2%	1,449	1,886	-2,236	-1,391	-3,628	2,329	3,033	-6,660
34	8/1/03	17A	230	238	621,697	10.88	225	150.8	8/11/03		x	100.0%	83.8%	1,368	1,787	-2,236	-3,159	-5,395	1,852	2,385	-7,780
35	10/2/03	18A	230	238	645,948	11.05	243	145.0	10/4/03		x	100.0%	85.6%	2,032	2,577	-2,236	-5,738	-7,973	1,088	1,380	-9,352
36	12/1/03	19A	230	238	650,357	11.11	308	137.0	12/10/03		x	100.0%	85.2%	1,378	1,752	-2,236	-7,488	-9,725	852	930	-10,555

* STRAP version 5.0

Tier 2, masses and ballistic numbers from LaRC 3/95
ER Atm; "A" Altitude Strategy
BN Option = WORST_CASE
Skip-Cycle Calculations = TRUE
Skip-Cycle Interval = 270
SC Min. Alt. Strategy = L
SC Min. Alt. Lifetime = 90
SC Min. Alt. Lifetime Altitude = 150
Semi-Annual Effect = TRUE
Geomagnetic Correction = TRUE
Solar Flux Source = TABLES
ATMOSPHERE MODEL = +2_SIGMA
FLUX DATA FILE = data_files/ML-SSP30425.DAT
AP DATA FILE = data_files/ML-SSP30425-AP.DAT

** Propellant numbers take into account efficiency of Bus being used and include 5% for Pre- and Post- docking maneuvers and 5% for attitude control during reboost

*** Bus ISP = 295 sec; each bus is delivered with 11,600 lbs of usable propellant

Table 6.3-4 Propellant Requirements for a Mean Atmosphere - Nominal Solar Cycle Start

Tier 2 Propellant Req'ts - Mean Atm. Case - Nominal Start									Reboost Propellant								Prop Balance After Reboost			Skip Cycle		Skip Cycle
#	Launch Date	Flight Name	Lower Alt. (nm)	Upper Alt. (nm)	Stage Mass (lbs)	Ballistic # (lbs/ft^2)	Lifetime (Days)	F10.7	Reboost Date	Alt Bus	Zen. Bus	Alt Bus Eff.	Zen. Bus Eff.	Strap Output*	Reboost Prop**	Alt Bus***	Zen. Bus***	Total Prop Available	Strap* SC Prop (lbs)	Total SC Prop** (lbs)	Prop Margin
1	2/1/98	1A	189.6	189.6	31,365	56.52	579	85.5	2/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	0	0	11,600
2	4/1/98	2A	197.8	197.8	58,642	36.89	362	93.7	4/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	107	117	11,483
3	6/1/98	3A	194.5	194.5	82,893	42.83	290	98.9	6/12/98	x		100.0%	N/A	0	0	11,600	0	11,600	249	274	11,326
4	9/1/98	4A	190	208	115,301	37.89	220	107.2	9/11/98	x		88.7%	N/A	758	950	10,650	0	10,650	0	0	10,650
5	11/1/98	5A	205	220	145,363	10.00	116	113.2	11/12/98	x		98.5%	N/A	764	868	9,782	0	9,782	1,198	1,361	8,420
6	12/1/98	6A	215	222	158,070	10.84	163	116.2	12/15/98	x		98.5%	N/A	396	441	9,340	0	9,340	1,282	1,430	7,911
7	2/1/99	UF-1	215	222	173,282	12.01	173	122.0	2/15/99	x		100.0%	N/A	433	476	8,864	0	8,864	1,301	1,431	7,433
8	4/1/99	7A	215	222	194,666	12.87	188	126.5	4/12/99	x		100.0%	N/A	479	527	8,338	0	8,338	1,420	1,562	6,775
9	6/1/99	8A	215	220	224,880	14.43	184	131.0	6/10/99	x		100.0%	N/A	440	484	7,853	0	7,853	1,473	1,621	6,233
10	8/1/99	BF-2	215	222	253,529	16.35	187	135.6	8/10/99		x	87.9%	100.0%	804	684	7,853	10,938	18,789	1,377	1,515	17,274
11	10/1/99	UF-2	215	222	262,347	16.62	198	138.6	10/15/99		x	88.5%	100.0%	669	738	7,853	10,200	18,053	1,388	1,527	16,526
12	12/1/99	9A	215	222	282,189	16.56	209	143.2	12/10/99		x	89.0%	100.0%	722	795	7,853	9,405	17,258	1,533	1,687	15,571
13	2/1/00	10A	215	221	308,644	17.99	214	145.6	2/15/00	x		92.3%	100.0%	720	852	7,001	9,405	16,406	1,400	1,658	14,749
14	4/1/00	11A	215	226	339,508	18.01	229	147.2	4/12/00	x		92.3%	100.0%	1,327	1,571	5,430	9,405	14,835	925	1,095	13,741
15	6/1/00	UF-3	220	224	339,508	18.50	276	148.1	6/15/00	x		92.2%	100.0%	524	621	4,809	9,405	14,214	856	1,013	13,201
16	8/1/00	1 J/A	220	234	357,145	19.47	268	148.7	8/13/00	x		93.1%	100.0%	1,754	2,059	2,750	9,405	12,155	0	0	12,155
17	10/1/00	12A	230	235	380,214	20.29	424	146.8	10/11/00	x		93.8%	100.0%	673	785	1,965	9,405	11,370	0	0	11,370
18	12/1/00	12Ap	230	234	388,828	16.17	388	145.1	12/18/00	x		93.6%	100.0%	596	698	1,268	9,405	10,673	0	0	10,673
19	2/1/01	UF-4p	230	234	388,828	15.88	363	144.9	2/15/01	x		93.4%	100.0%	630	739	530	9,405	9,935	0	0	9,935
20	4/1/01	BF-3	230	235	396,928	15.88	372	144.2	4/10/01		x	93.4%	100.0%	577	744	11,600	8,861	20,291	0	0	20,281
21	6/1/01	13A	230	233	434,308	16.57	388	142.7	6/12/01		x	93.5%	100.0%	519	571	11,600	8,090	19,690	0	0	19,690
22	8/1/01	13Ap	230	234	434,308	10.08	482	142.1	8/10/01		x	100.0%	91.7%	577	686	11,600	7,404	19,004	0	0	19,004
23	10/2/01	UF-5p	230	234	434,308	10.08	479	140.1	10/16/01		x	100.0%	91.7%	623	742	11,600	6,682	18,282	0	0	18,282
24	12/1/01	1J	230	236	467,375	10.74	289	136.8	12/10/01		x	100.0%	80.2%	992	1,336	11,600	5,326	16,926	938	1,263	15,662
25	2/1/02	2E	230	236	489,580	10.82	289	134.3	2/12/02		x	100.0%	84.2%	1,038	1,337	11,600	3,988	15,588	686	884	14,705
26	4/1/02	UF-6p	230	235	489,580	10.82	308	131.6	4/15/02		x	100.0%	84.2%	908	1,189	11,600	2,819	14,419	531	684	13,735
27	6/1/02	2J/A	230	234	498,240	11.29	317	128.3	6/15/02		x	100.0%	76.7%	674	947	11,600	1,873	13,473	274	385	13,087
28	8/1/02	15A	230	236	529,104	9.45	268	126.5	8/12/02		x	100.0%	86.0%	1,101	1,390	11,600	483	12,083	951	1,201	10,881
29	10/1/02	BF-4	233	238	529,104	9.45	295	123.5	10/15/02	x		100.0%	89.9%	1,224	1,347	10,253	11,600	21,853	508	669	21,184
30	12/1/02	UF-7p	230	235	529,104	9.43	318	121.5	12/15/02	x		100.0%	88.2%	939	1,033	9,221	11,600	20,821	395	434	20,387
31	2/1/03	14A	230	235	551,150	9.86	328	119.5	2/12/03	x		100.0%	83.7%	1,003	1,103	8,118	11,600	19,718	0	0	19,718
32	4/1/03	1E	230	234	588,424	10.29	371	118.3	4/12/03	x		100.0%	80.9%	906	997	7,121	11,600	18,721	0	0	18,721
33	6/1/03	16A	230	233	612,879	10.72	421	112.9	6/9/03	x		100.0%	83.2%	728	801	6,320	11,600	17,920	0	0	17,920
34	8/1/03	17A	230	233	621,697	10.88	450	109.5	8/11/03	x		100.0%	83.8%	682	751	5,569	11,600	17,169	0	0	17,169
35	10/2/03	18A	230	235	645,848	11.05	488	108.4	10/4/03	x		100.0%	85.6%	1,059	1,165	4,404	11,600	16,004	0	0	16,004
36	12/1/03	19A	230	233	650,357	11.11	522	103.4	12/10/03	x		100.0%	85.2%	740	814	3,590	11,600	15,190	0	0	15,190

* STRAP version 5.0
Tier 2, masses and ballistic numbers from LaRC 3/95
ER Atm; "A" Altitude Strategy
BN Option = WORST_CASE
Skip-Cycle Calculations = TRUE
Skip-Cycle Interval = 270
SC Min. Alt. Strategy = L
SC Min. Alt. Lifetime = 90
SC Min. Alt. Lifetime Altitude = 150
Semi-Annual Effect = TRUE
Geomagnetic Correction = TRUE
Solar Flux Source = TABLES
ATMOSPHERE MODEL = MEAN
FLUX DATA FILE = data_files\ML-SSP30425.DAT
AP DATA FILE = data_files\ML-SSP30425-AP.DAT

** Propellant numbers take into account efficiency of Bus being used and include 5% for Pre- and Post- docking maneuvers and 5% for attitude control during reboost

*** Bus ISP = 295 sec; each Bus is delivered with 11,600 lbs of usable propellant

Table 6.3-5 Propellant Requirements for a +2σ Atmosphere - Late Solar Cycle Start

Tier 2 Propellant Req'ts - +2 Sigma Atm. Case - Late Start									Reboost Propellant							Prop Balance After Reboost			Skip Cycle		Skip Cycle
#	Launch Date	Flight Name	Lower Alt. (nm)	Upper Alt. (nm)	Stage Mass (lbs)	Ballistic # (lbs/ft**2)	Lifetime (Days)	F10.7	Reboost Date	Alt Bus	Zen. Bus	Alt Bus Eff.	Zen. Bus Eff.	Strap * Output	Reboost Prop**	Alt Bus***	Zen. Bus***	Total Prop Available	Strap* SC Prop (lbs)	Total SC Prop** (lbs)	Prop Margin
1	2/1/98	1A	157.8	187.5	31,365	56.52	533	76.2	2/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	0	0	11,600
2	4/1/98	2A	198.5	198.5	58,642	36.89	357	79.8	4/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	144	158	11,442
3	6/1/98	3A	193.8	193.8	82,803	42.83	294	84.1	6/12/98	x		100.0%	N/A	0	0	11,600	0	11,600	344	378	11,222
4	9/1/98	4A	180	208	115,301	37.80	213	97.9	9/11/98	x		86.7%	N/A	747	936	10,664	0	10,664	108	133	10,531
5	11/1/98	5A	205	219	145,083	10.00	111	107.7	11/12/98	x		88.5%	N/A	761	865	9,799	0	9,799	1,684	1,890	7,909
6	12/1/98	6A	215	223	158,070	10.84	140	114.5	12/15/98	x		98.5%	N/A	431	480	9,319	0	9,319	1,909	2,129	7,190
7	2/1/99	UF-1	215	224	173,282	12.01	132	129.1	2/15/99	x		100.0%	N/A	535	589	8,730	0	8,730	2,095	2,305	6,425
8	4/1/99	7A	215	224	194,608	12.87	149	143.4	4/12/99	x		100.0%	N/A	627	690	8,040	0	8,040	2,436	2,680	5,360
9	6/1/99	8A	215	222	224,800	14.43	144	151.7	6/10/99	x		100.0%	N/A	603	663	7,377	0	7,377	2,760	3,036	4,340
10	8/1/99	BF-2	215	224	253,529	16.35	132	160.1	8/10/99		x	87.9%	100.0%	844	929	7,377	10,671	18,048	2,979	3,277	14,771
11	10/1/99	UF-2	215	225	282,347	16.62	135	169.1	10/15/99		x	88.5%	100.0%	963	1,059	7,377	9,612	16,989	3,285	3,613	13,376
12	12/1/99	9A	215	226	282,190	16.56	130	177.1	12/10/99		x	89.0%	100.0%	1,141	1,255	7,377	8,358	15,734	3,853	4,238	11,496
13	2/1/00	10A	215	228	308,644	17.90	119	191.5	2/15/00	x		92.3%	100.0%	1,211	1,433	5,944	8,358	14,302	4,097	4,848	9,453
14	4/1/00	11A	215	230	330,508	18.01	137	198.9	4/12/00		x	92.3%	100.0%	1,885	2,073	5,944	6,284	12,229	4,193	4,612	7,617
15	6/1/00	UF-3	220	228	330,508	18.50	147	204.2	6/15/00		x	92.2%	100.0%	1,033	1,136	5,944	5,148	11,092	4,309	4,740	6,352
16	8/1/00	1 J/A	220	238	357,145	19.47	129	214.8	8/13/00		x	93.1%	100.0%	2,319	2,551	5,944	2,597	8,541	3,125	3,438	5,104
17	10/1/00	12A	230	241	390,214	20.29	175	221.8	10/11/00	x		93.8%	100.0%	1,584	1,847	4,097	2,597	6,694	3,289	3,811	2,883
18	12/1/00	12Ap	230	241	398,828	16.17	147	229.9	12/18/00	x		93.6%	100.0%	1,507	1,761	2,336	2,597	4,933	4,810	5,386	-453
19	2/1/01	UF-4p	230	241	398,828	15.88	141	233.7	2/15/01	x		93.4%	100.0%	1,607	1,881	455	2,597	3,052	4,871	5,468	-2,416
20	4/1/01	BF-3	230	243	398,928	15.88	153	238.8	4/10/01	x		93.4%	100.0%	1,812	2,121	8,473	2,597	12,678	4,842	5,434	6,842
21	6/1/01	13A	230	240	434,308	18.57	149	245.2	6/12/01	x		93.5%	100.0%	1,499	1,753	7,720	2,597	10,323	4,178	4,884	5,439
22	8/1/01	13Ap	230	241	434,308	10.08	157	243.3	8/16/01	x		100.0%	91.7%	1,640	1,805	5,921	2,597	8,518	4,001	4,401	4,117
23	10/2/01	UF-5p	230	241	434,308	10.08	160	245.7	10/16/01	x		100.0%	91.7%	1,781	1,959	3,962	2,597	6,559	3,788	4,167	2,392
24	12/1/01	1J	230	247	467,375	10.74	101	239.4	12/10/01	x		100.0%	80.2%	2,777	3,055	907	2,597	3,504	7,413	8,155	-4,651
25	2/1/02	2E	230	247	488,580	10.82	95	232.9	2/12/02	x		100.0%	84.2%	2,918	3,210	-2,303	2,597	294	7,128	7,841	-7,547
26	4/1/02	UF-6p	230	248	488,580	10.82	110	233.1	4/15/02		x	100.0%	84.2%	2,678	3,449	-2,303	-852	-3,155	8,923	8,914	-12,069
27	6/1/02	2J/A	230	242	498,240	11.29	119	228.1	6/15/02	x		100.0%	78.7%	2,105	2,316	-4,619	-852	-5,471	6,960	7,656	-13,128
28	8/1/02	15A	230	248	529,104	9.45	80	227.6	8/12/02		x	100.0%	80.0%	3,333	4,209	-4,619	-5,061	-9,680	9,230	10,393	-20,073
29	10/1/02	BF-4	230	249	529,104	9.45	85	225.9	10/15/02		x	100.0%	89.9%	3,673	4,645	-4,619	6,955	2,336	7,659	9,671	-7,335
30	12/1/02	UF-7p	230	245	529,104	9.43	102	218.6	12/15/02		x	100.0%	80.2%	2,850	3,591	-4,619	3,364	-1,255	7,345	9,255	-10,509
31	2/1/03	14A	230	245	551,150	9.86	100	212.0	2/12/03		x	100.0%	83.7%	2,985	3,839	-4,619	-475	-5,093	6,879	8,907	-14,000
32	4/1/03	1E	230	243	586,424	10.29	124	204.0	4/12/03		x	100.0%	80.9%	2,782	3,717	-4,619	-4,192	-8,811	6,573	8,782	-17,563
33	6/1/03	16A	230	241	612,879	10.72	139	200.4	6/9/03		x	100.0%	83.2%	2,324	3,028	-4,619	-7,219	-11,837	8,221	8,100	-19,936
34	8/1/03	17A	230	240	621,697	10.88	130	195.7	8/11/03		x	100.0%	83.8%	2,230	2,884	-4,619	-10,102	-14,720	5,708	7,382	-22,103
35	10/2/03	18A	230	244	645,948	11.05	135	191.5	10/4/03		x	100.0%	85.6%	3,305	4,191	-4,619	-14,293	-18,912	4,962	6,186	-25,098
36	12/1/03	19A	230	240	650,357	11.11	159	182.9	12/10/03		x	100.0%	85.2%	2,345	2,987	-4,619	-17,280	-21,899	4,294	5,470	-27,369

* STRAP version 5.0
Tier 2, masses and ballistic numbers from LaRC 3/95
ER Atm; "A" Altitude Strategy
BN Option = WORST_CASE
Skip-Cycle Calculations = TRUE
Skip-Cycle Interval = 270
SC Min. Alt. Strategy = L
SC Min. Alt. Lifetime = 90
SC Min. Alt. Lifetime Altitude = 150
Semi-Annual Effect = TRUE
Geomagnetic Correction = TRUE
Solar Flux Source = TABLES
ATMOSPHERE MODEL = +2_SIGMA
FLUX DATA FILE = data_files\LT-SSP30425.DAT
AP DATA FILE = data_files\LT-SSP30425-AP.DAT

** Propellant numbers take into account efficiency of Bus being used and include 5% for Pre- and Post- docking maneuvers and 5% for attitude control during reboost

*** Bus ISP = 295 sec; each Bus is delivered with 11,600 lbs of usable propellant

Table 6.3-6 Propellant Requirements for a Mean Atmosphere - Late Solar Cycle Start

Tier 2 Propellant Req's - Mean Atm. Case - Late Start									Reboost Propellant							Prop Balance After Reboost			Skip Cycle		Skip Cycle
#	Launch Date	Flight Name	Lower Alt. (nm)	Upper Alt. (nm)	Stage Mass (lbs)	Ballistic # (lbs/ft**2)	Lifetime (Days)	F10.7	Reboost Date	Alt Bus	Zen. Bus	Alt Bus Eff.	Zen. Bus Eff.	Strap* Output	Reboost Prop**	Alt Bus***	Zen. Bus***	Total Prop Available	Strap* SC Prop (lbs)	Total SC Prop** (lbs)	Prop Margin
1	2/1/98	1A	198.3	198.2	31,395	55.52	721	71.1	2/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	0	0	11,600
2	4/1/98	2A	195.0	194.8	58,642	36.89	492	72.2	4/10/98	x		100.0%	N/A	0	0	11,600	0	11,600	0	0	11,600
3	6/1/98	3A	192.8	192.7	82,883	42.83	429	73.6	6/12/98	x		100.0%	N/A	0	0	11,600	0	11,600	0	0	11,600
4	8/1/98	4A	190	207	115,301	37.89	355	77.0	9/11/98	x		98.7%	N/A	697	874	10,726	0	10,726	0	0	10,726
5	11/1/98	5A	205	217	145,083	10.00	189	80.1	11/12/98	x		98.5%	N/A	651	740	9,986	0	9,986	438	498	9,491
6	12/1/98	6A	215	219	158,070	10.84	283	82.0	12/15/98	x		98.5%	N/A	213	237	9,749	0	9,749	503	581	9,188
7	2/1/99	UF-1	215	219	173,282	12.01	272	86.2	2/15/99	x		100.0%	N/A	238	260	9,489	0	9,489	528	581	8,908
8	4/1/99	7A	215	219	194,808	12.87	275	91.0	4/12/99	x		100.0%	N/A	270	297	9,193	0	9,193	639	703	8,490
9	6/1/99	8A	215	218	224,889	14.43	272	96.3	6/10/99	x		100.0%	N/A	258	284	8,909	0	8,909	667	733	8,176
10	8/1/99	SF-2	215	219	253,529	19.35	268	101.6	8/16/99	x		87.9%	100.0%	370	458	9,451	11,600	20,051	619	786	19,295
11	10/1/99	UF-2	215	219	262,347	18.62	281	107.2	10/15/99	x		88.5%	100.0%	427	525	7,926	11,600	19,526	766	942	18,584
12	12/1/99	9A	215	220	282,188	16.56	283	113.2	12/10/99	x		89.0%	100.0%	494	605	7,321	11,600	18,921	1,029	1,257	17,664
13	2/1/00	10A	215	220	308,044	17.99	281	119.3	2/15/00	x		92.3%	100.0%	525	622	6,700	11,600	18,300	1,013	1,198	17,101
14	4/1/00	11A	215	224	330,508	18.01	288	124.3	4/12/00	x		92.3%	100.0%	1,155	1,368	5,333	11,600	16,933	674	797	16,136
15	6/1/00	UF-3	220	223	330,508	18.50	300	128.6	6/15/00	x		92.2%	100.0%	419	498	4,837	11,600	16,437	721	854	15,583
16	8/1/00	1J/A	220	233	357,145	19.47	284	133.3	8/13/00	x		93.1%	100.0%	1,681	1,974	2,863	11,600	14,463	0	0	14,463
17	10/1/00	12A	230	234	380,214	20.28	421	137.6	10/11/00	x		93.8%	100.0%	618	720	2,143	11,600	13,743	0	0	13,743
18	12/1/00	12Ap	230	234	386,828	16.17	355	141.4	12/18/00	x		93.8%	100.0%	577	674	1,469	11,600	13,069	104	122	12,947
19	2/1/01	UF-4p	230	234	386,828	15.88	344	144.6	2/15/01	x		93.4%	100.0%	628	735	734	11,600	12,334	180	187	12,147
20	4/1/01	SF-3	230	235	366,828	15.89	347	146.7	4/10/01		x	93.4%	100.0%	665	764	11,600	10,836	22,436	166	183	22,253
21	6/1/01	13A	230	234	434,308	18.57	345	147.7	6/12/01		x	93.5%	100.0%	549	604	11,600	10,232	21,832	0	0	21,832
22	8/1/01	13Ap	230	234	434,306	10.08	408	148.4	8/18/01		x	100.0%	91.7%	623	742	11,600	9,489	21,089	0	0	21,089
23	10/2/01	UF-5p	230	234	434,308	10.08	403	148.2	10/18/01		x	100.0%	91.7%	685	816	11,600	8,673	20,273	0	0	20,273
24	12/1/01	1J	230	237	467,375	10.74	243	145.7	12/10/01		x	100.0%	80.2%	1,115	1,501	11,600	7,172	18,772	1,811	2,574	16,198
25	2/1/02	2E	230	237	489,580	10.82	248	144.9	2/12/02		x	100.0%	84.2%	1,207	1,554	11,600	5,618	17,218	1,737	2,237	14,981
26	4/1/02	UF-6p	230	238	489,580	10.82	249	144.7	4/15/02		x	100.0%	84.2%	1,090	1,411	11,600	4,207	15,807	1,640	2,112	13,696
27	6/1/02	2J/A	230	235	488,240	11.29	255	143.5	6/15/02		x	100.0%	78.7%	833	1,170	11,600	3,037	14,637	1,478	2,072	12,565
28	8/1/02	15A	230	237	529,104	9.45	213	142.3	8/12/02		x	100.0%	86.0%	1,383	1,759	11,600	1,278	12,878	2,318	2,827	9,851
29	10/1/02	SF-4	230	238	529,104	9.45	213	141.3	10/15/02	x		100.0%	99.0%	1,599	1,726	9,874	11,600	21,474	2,304	2,205	19,269
30	12/1/02	UF-7p	230	238	529,104	9.43	245	138.4	12/15/02	x		100.0%	80.2%	1,190	1,309	8,565	11,600	20,165	1,860	2,046	18,119
31	2/1/03	14A	230	238	551,150	9.86	253	135.5	2/12/03	x		100.0%	83.7%	1,286	1,415	7,150	11,600	18,750	1,438	1,582	17,168
32	4/1/03	1E	230	238	588,424	10.29	273	133.0	[illegible]12/03	x		100.0%	80.9%	1,189	1,308	5,842	11,600	17,442	1,082	1,190	16,252
33	6/1/03	16A	230	234	612,879	10.72	287	128.8	[illegible]/9/03	x		100.0%	83.2%	988	1,084	4,778	11,600	16,378	779	857	15,521
34	8/1/03	17A	230	234	621,687	10.89	303	127.3	8/11/03	x		100.0%	83.8%	938	1,030	3,748	11,600	15,348	485	534	14,814
35	10/2/03	18A	230	238	645,948	11.05	326	125.1	10/4/03	x		100.0%	85.6%	1,472	1,619	2,129	11,600	13,729	0	0	13,729
36	12/1/03	19A	230	235	650,357	11.11	383	122.3	12/10/03	x		100.0%	85.2%	1,059	1,165	963	11,600	12,563	0	0	12,563

* STRAP version 5.0
Tier 2, masses and ballistic numbers from LaRC 3/95
ER Atm; "A" Altitude Strategy
BN Opt. n = WORST_CASE
Skip-Cycle Calculations = TRUE
Skip-Cycle Interval = 270
SF Min. Alt. Strategy = L
SC Min. Alt. Lifetime = 90
SC Min. Alt. Lifetime Altitude = 190
Semi-Annual Effect = TRUE
Geomagnetic Correction = TRUE
Solar Flux Source = TABLES
ATMOSPHERE MODEL = MEAN
FLUX DATA FILE = data_files\LT-SSP30425.DAT
AP DATA FILE = data_files\LT-SSP30425-AP.DAT

** Propellant numbers take into account efficiency of Bus being used and include 5% for Pre- and Post- docking maneuvers and 5% for attitude control during reboost

*** Bus ISP = 285 sec; each Bus is delivered with 11,600 lbs of usable propellant

6.4 Microgravity Rack Analysis

The steady state microgravity levels were computed at the center of each of the ISPR racks in the US Lab for each assembly stage. A $+2\sigma$ day of launch atmosphere was assumed using the assembly altitude. The atmosphere tables for geomagnetic index and solar flux values are provided in Appendix A. Using an early solar cycle start date the results for the ceiling, port and starboard US Lab ISPR racks are depicted in the plots in figures 6.4-1, 6.4-2, & 6.4-3, respectively, for the entire assembly sequence. It was not possible to determine the microgravity results for Stage 16 since this stage was not controllable in the atmosphere described above using currently designed control algorithms (see Section 5.16.4).

The results show the ceiling racks consistently provide the lowest micro-g during the assembly build. The ceiling experiment racks meet the 1 μg requirement in over half the assembly flights. In general, the results indicate that the Tier 2 Station does not meet the 1 μg requirement for 50% of the experiment racks throughout the assembly sequence, however it does meet this requirement by assembly complete. It also provides at least 4 (32.5%) racks in the 1 μg environment in 20 (out of 31) of the assembly flights.

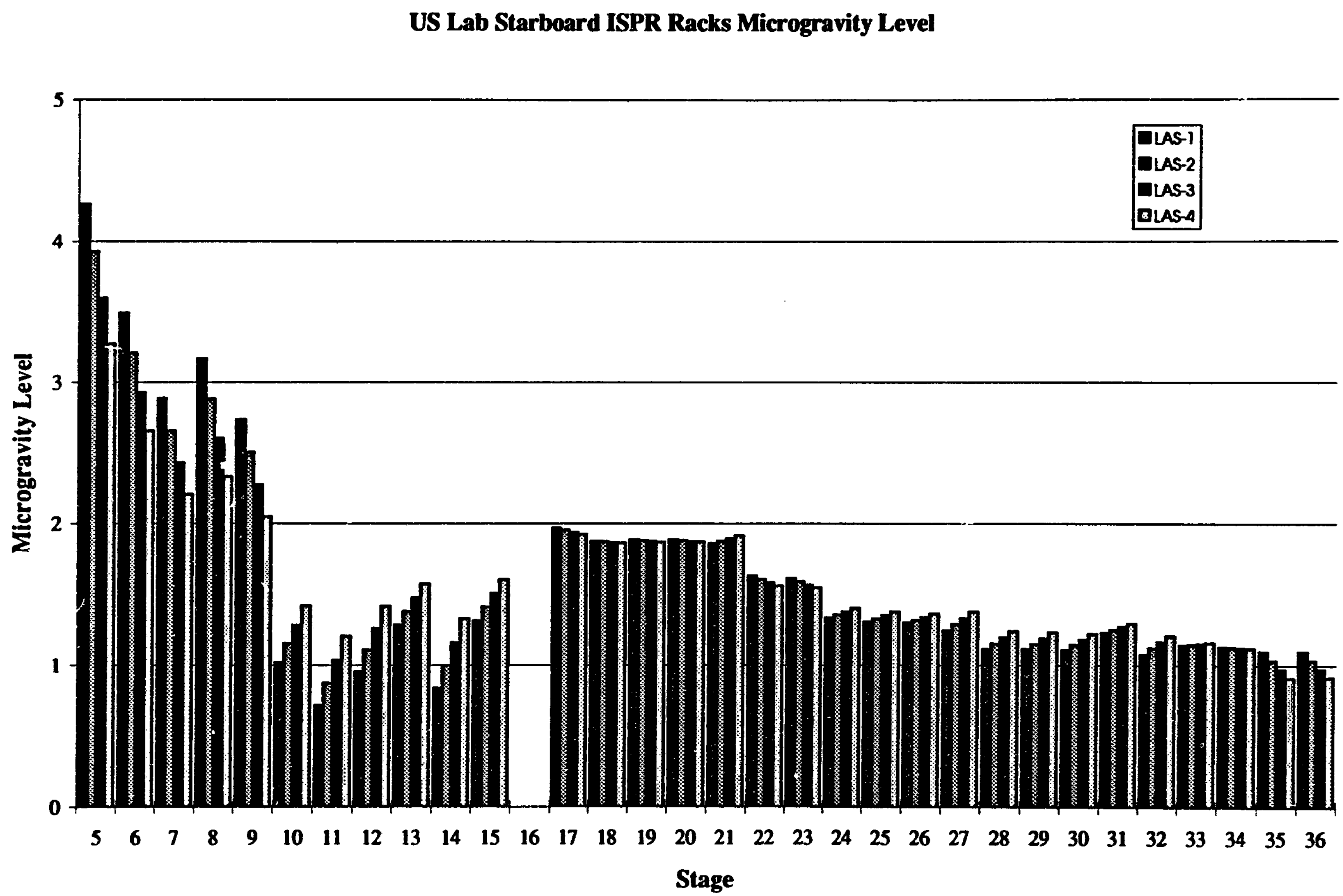


Figure 6.4-1 US Lab Steady State Microgravity Level for the Starboard ISPR Racks by Stage

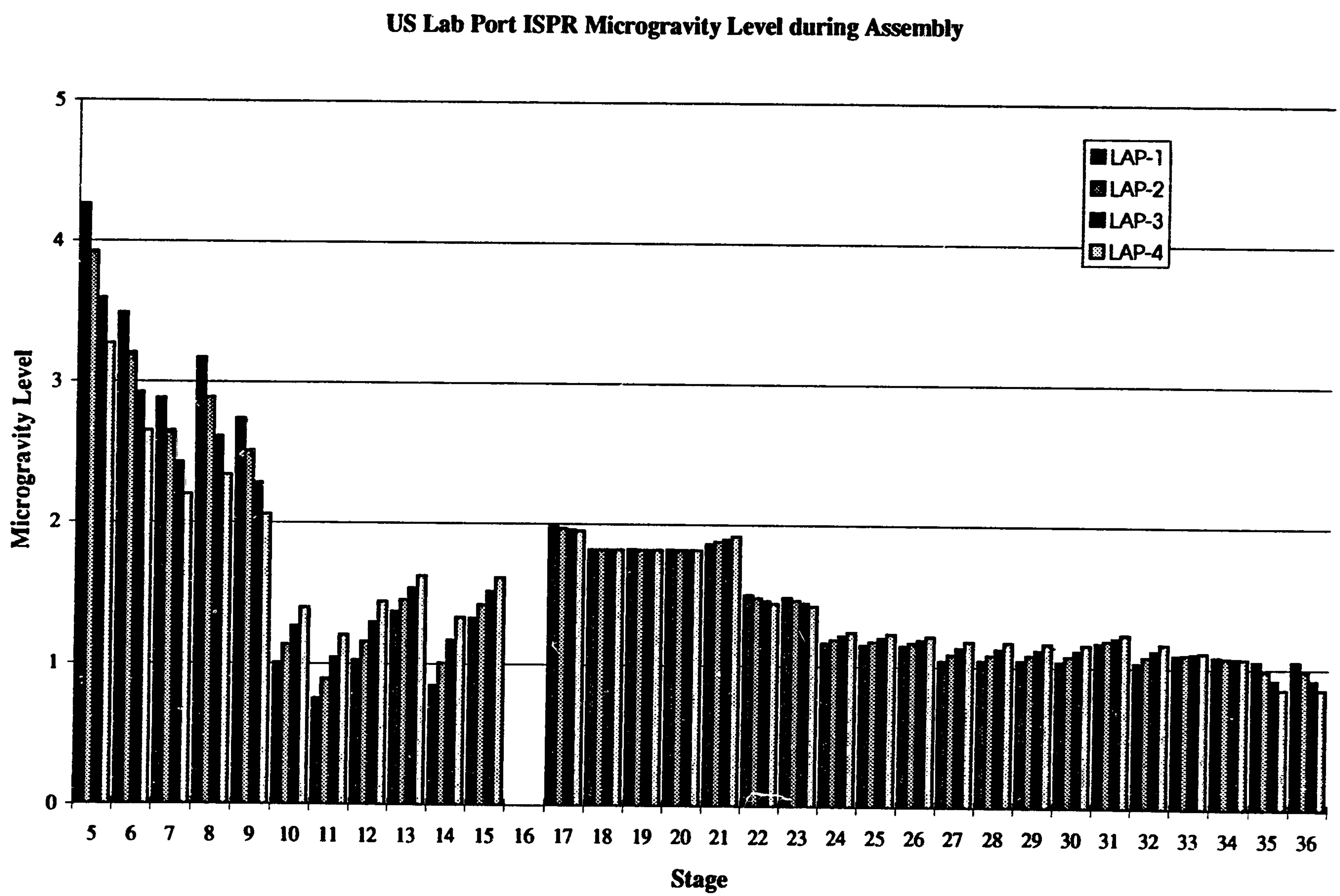
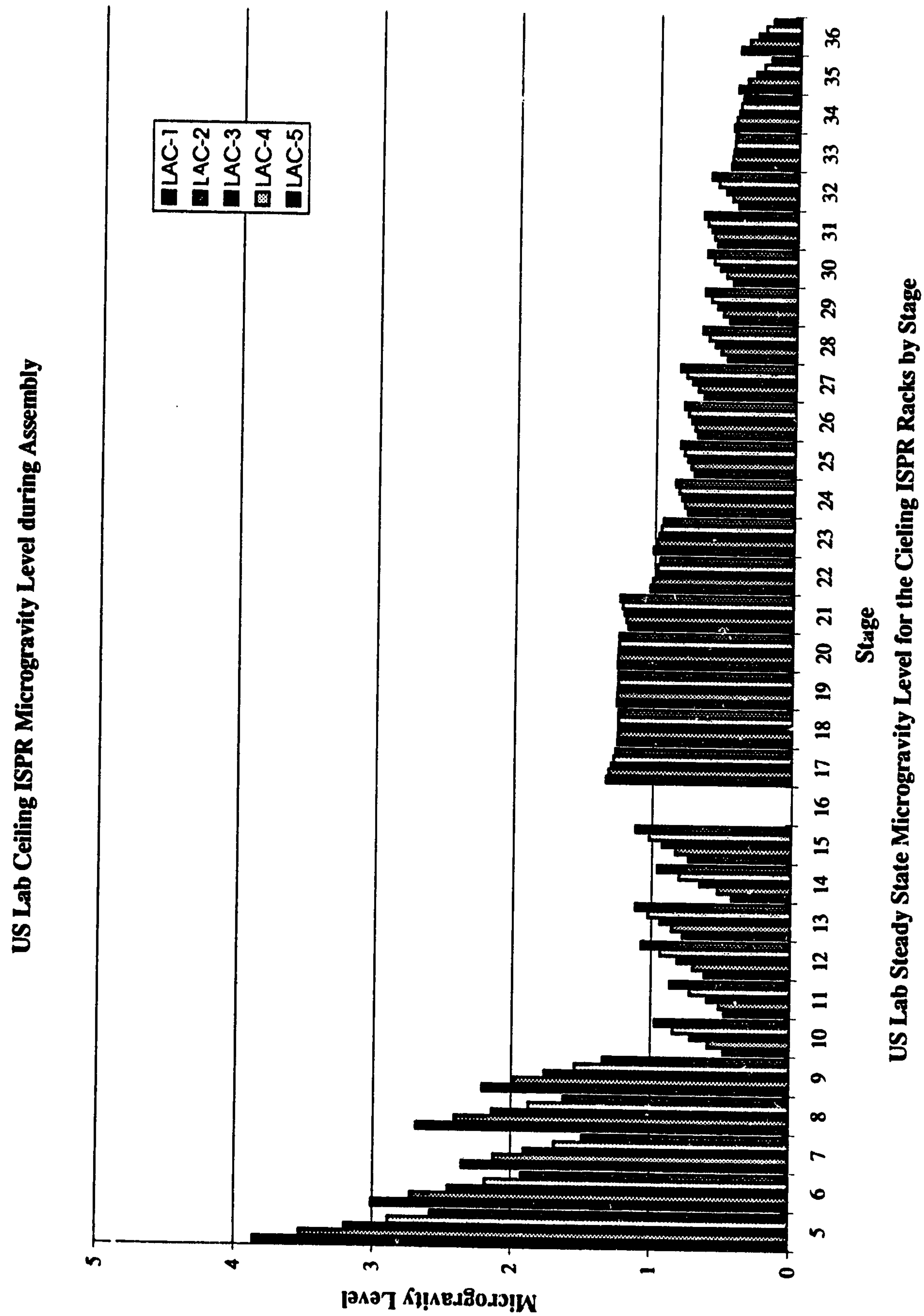


Figure 6.4-2 US Lab Steady State Microgravity Level for the Port ISPR Racks by Stage


US Lab Ceiling ISPR Microgravity Level during Assembly
LAC-1
LAC-2
LAC-3
LAC-4
LAC-5
Microgravity Level
0
1
2
3
4
5
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
Stage
US Lab Steady State Microgravity Level for the Cieling ISPR Racks by Stage

7. Conclusions

The proposed assembly sequence utilizing the Bus-1 incorporates significant changes into the baseline international Space Station assembly sequence. The changes are required to replace Russian supplied functionality in the areas of propulsion, logistics, early station based EVA and initial spacecraft functionality. Changes include the elimination of all Russian systems, the utilization of the Bus-1 for propulsion and fuel logistics, and modification of the baseline assembly sequence operations and schedule to enable Shuttle based EVA only for assembly. Table 7-1 summarizes the issues and concerns associated with the proposed assembly sequence. For each issue and stage, a value of one to three has been assigned to rank the difficulty of addressing the issue. A value of one indicates an issue that could be remedied through minor operational changes or waivers. A value of two indicates that the issue will require significant increases in Shuttle performance or additional hardware development. A value of three indicates that there is no apparent hardware or operational workaround to resolve the issue.

Several stages require baseline hardware modifications. Stage 1 requires the development of the Bus-1, extender truss, solar arrays and an additional PDGF and structural CBM interface. Stage 3 requires the addition of pressurized gas carriers and their associated interfaces. Stage 10 requires a second extender truss with a P6/Z1 interface with PDGFs on the new extender truss and on top of the S0 segment. Stage 13 has a unique docking orientation that requires the PMA on the nadir side of Node 1 to be clocked 90 degrees. Stage 35 and beyond require special operations or configuration changes to make a secondary Shuttle available.

The configurations associated with the proposed assembly sequence have flight characteristics that are significantly different than the baseline. Stages 2 and 3 fly in a solar inertial mode similar to Stage 2 in the baseline. Thermal loads are a concern for any inertial flight mode but Stage 3 in the proposed sequence may induce thermal loads on the Z1 truss that differ from the baseline. Stages 4 to 16 all have pitch attitudes that exceed ±15 degrees with and without a docked Shuttle. These attitudes could expose minimally shielded portions of the station to orbital debris along with impacting the communications and tracking system. These large pitch attitudes most significantly impact the non-mated configurations due to longer exposure to the environment. The mated configurations last for only a week or so 6 times a year therefore the potential for debris damage at large pitch angles is significantly reduced for Stages 17 to 36 since the ±15 degree limit is only violated when an orbiter is attached. The attitudes associated with the proposed sequence are directly related to the inertia properties of the buildup. The closeness of all three body axes inertias during the earlier stages of the sequence coupled with large pitch aerodynamic torques lead to the large pitch flight attitudes.

The poor microgravity environment associated with Stages 6 to 16 is a direct function of the pitch attitude. Significantly improving the microgravity environment on these stages would require a change in mass properties. The microgravity environment could probably be improved for Stages 17 to 27 by relocating the zenith bus to the nadir port of node 1 thus lowering the center of mass so that it is closer to the center of the lab. This would require an additional structural CBM interface to be attached to the second extender truss. The bus would have to be relocated to the zenith position before the installation of the habitation module.

Stages 4 to 11 had orbital lifetimes of less than 90 days at the assembly rendezvous altitude. The short lifetimes result from low ballistic coefficients combined with low altitudes. The ballistic coefficients cannot be improved since the solar arrays need to articulate to get sufficient power. Higher assembly altitudes would require additional Shuttle lift performance or offloading of station components. Several stages had insufficient skip cycle reserve or negative fuel margins but this can be corrected by adding and remanifesting bus logistics flights.

There is a potential for minor plume impingement from the aft bus thrusters on some of the radiators. Utilizing a longer extender truss as proposed in Section 3.3 would reduce the potential for plume impingement greatly. Doubling the length of the aft extender would substantially improve the mass properties throughout the build sequence resulting in smaller flight attitudes, superior microgravity environments and easier to control configurations. The cost of the longer extender would be an additional Shuttle flight along with complex installation and changeout operations for the aft bus.

Table 7-1 Issues and Concerns Summary

Stage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Issues and Concerns	1A	2A	3A	4A	5A	6A	UF1	7A	8A	BUS	UF2	9A	10A	11A	UF3	1JA	12A	12Ap	UF4p	LF1	13A	13Ap	UF5p	1J	2E	UF6p	2JA	15A	LF2	UF7p	14A	1E	16A	17A	18A	19A
Hardware/Operations Development and Modifications	2		2							2			2																						2	2
Solar Inertial Flight Mode		1	1																																	
Lifetime at Assembly Rendezvous Altitude is Less Than 90 Days to 150 nmi				2	2	2	2	2	2	2	2																									
Flight attitude that exceeds +/- 15 degrees				3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Difficulty in controlling configuration with CMGs					1											2																				
Minor Plume Impingement Potential					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Poor Microgravity Environment						3	3	3	3				3		3	3	2	2	2	2	2	2	2	2	2	2										
Insufficient Skip Cycle Propellant Reserve									1							1	1	1	1		1						1	1								
Negative Margin on Shuttle Manifest												1		1		1	1							1												
Stage Issues and Concerns Total	2	1	3	5	7	9	9	9	10	8	6	5	9	5	7	11	6	5	5	4	5	4	4	5	4	4	3	3	2	2	2	2	2	2	4	4

Appendix A

Atmosphere Tables

Early Start Date (7/95)

	Solar Flux			Geomagnetic Index		
DATE	-2 sigma	mean	+2 sigma	-2 sigma	mean	+2 sigma
7/95	67.0	69.6	73.3	7.6	9.5	11.5
8/95	67.0	69.7	73.4	7.7	9.6	11.7
9/95	67.0	70.0	74.0	7.7	9.7	11.8
10/95	67.0	70.4	74.5	7.6	9.7	11.9
11/95	67.0	70.7	74.9	7.4	9.7	11.9
12/95	67.1	71.1	76.2	7.3	9.9	12.2
1/96	67.2	71.6	78.4	7.2	10.0	12.5
2/96	67.3	72.2	79.8	7.3	10.3	12.9
3/96	67.4	72.8	81.5	7.8	10.6	13.3
4/96	67.5	73.6	84.1	8.1	10.9	14.1
5/96	67.7	74.5	87.7	8.2	11.2	15.1
6/96	67.9	75.7	93.4	8.3	11.5	15.7
7/96	68.0	77.0	97.9	8.3	11.8	15.9
8/96	68.0	78.4	101.7	8.3	12.0	16.4
9/96	68.0	80.1	107.7	8.5	12.3	17.4
10/96	68.0	82.0	114.5	8.4	12.7	18.4
11/96	68.1	84.0	121.1	8.5	12.9	18.7
12/96	68.4	86.2	129.1	8.7	13.1	18.8
1/97	68.5	88.5	137.6	9.0	13.2	18.6
2/97	68.6	91.0	143.4	9.3	13.2	18.3
3/97	68.8	93.7	147.6	9.7	13.2	18.1
4/97	68.7	96.3	151.7	9.5	13.4	18.4
5/97	68.8	98.9	155.7	9.3	13.5	18.4
6/97	69.2	101.6	160.1	9.0	13.5	17.6
7/97	69.7	104.4	164.8	9.0	13.6	17.1
8/97	70.1	107.2	169.1	9.1	13.6	17.4
9/97	70.6	110.2	173.0	9.4	13.6	17.4
10/97	70.7	113.2	177.1	9.8	13.8	18.5
11/97	71.3	116.2	186.1	10.0	14.0	19.9
12/97	72.2	119.3	191.5	10.0	14.1	19.9
1/98	72.6	122.0	194.3	10.1	14.1	19.9
2/98	73.3	124.3	196.9	10.4	14.1	20.1
3/98	73.9	126.5	199.6	10.2	14.2	20.4
4/98	74.1	128.6	204.2	10.3	14.2	20.8
5/98	74.4	131.0	210.6	10.6	14.1	20.9
6/98	74.5	133.3	214.8	10.6	14.0	21.0
7/98	74.6	135.6	217.2	10.5	14.0	21.2
8/98	74.5	137.6	221.6	10.4	14.1	21.6
9/98	74.1	139.6	226.9	10.6	14.1	22.1
10/98	73.6	141.4	229.9	10.8	14.0	22.2
11/98	73.5	143.2	231.7	10.7	13.7	21.0
12/98	73.6	144.6	233.7	10.4	13.4	20.1
1/99	74.0	145.6	235.6	10.5	13.3	19.8
2/99	75.1	146.7	238.8	10.7	13.3	19.3
3/99	75.8	147.2	242.8	10.8	13.3	19.2
4/99	76.5	147.7	245.2	11.0	13.4	19.0
5/99	78.1	148.1	244.5	10.7	13.3	18.8
6/99	80.1	148.4	243.3	10.8	13.4	18.6
7/99	82.5	148.7	244.7	10.6	13.4	18.6

Early Start Date (7/95)

8/99	84.0	148.2	245.7	10.2	13.4	18.3
9/99	85.5	146.8	243.3	10.6	13.5	18.2
10/99	87.9	145.7	239.4	11.3	13.8	18.7
11/99	89.5	145.1	235.0	11.4	14.1	19.2
12/99	92.2	144.9	232.9	11.3	14.2	19.6
1/00	93.8	144.9	233.3	11.3	14.4	20.3
2/00	94.9	144.7	233.1	11.5	14.6	21.0
3/00	95.0	144.2	231.2	11.6	14.8	21.4
4/00	94.7	143.5	229.1	11.6	14.8	21.2
5/00	94.9	142.7	228.1	11.8	14.7	20.4
6/00	96.5	142.3	227.6	12.1	14.8	20.7
7/00	97.3	142.1	226.7	12.2	15.1	21.9
8/00	96.8	141.3	225.6	12.0	15.2	22.7
9/00	96.0	140.1	223.0	11.6	15.1	22.7
10/00	96.0	138.4	218.6	11.2	15.1	22.3
11/00	96.6	136.8	215.2	11.2	15.1	21.7
12/00	96.7	135.5	212.0	11.2	15.1	21.5
1/01	95.1	134.3	206.9	11.2	15.1	22.1
2/01	95.0	133.0	204.0	11.3	15.5	23.1
3/01	96.3	131.6	203.6	11.3	15.6	23.5
4/01	96.5	129.8	200.4	11.2	15.6	23.4
5/01	94.7	128.3	196.8	11.1	15.7	23.3
6/01	93.6	127.3	195.7	10.8	15.5	23.1
7/01	93.5	126.5	194.8	10.9	15.7	22.2
8/01	91.9	125.1	191.5	11.1	15.6	22.1
9/01	88.7	123.5	187.4	11.7	15.6	22.2
10/01	86.6	122.3	182.9	11.6	15.8	22.5
11/01	87.8	121.5	178.6	11.5	15.9	22.6
12/01	86.5	120.5	176.3	11.3	15.8	22.5
1/02	85.9	119.5	174.9	11.3	15.7	21.6
2/02	85.0	117.9	171.1	11.3	15.4	21.0
3/02	83.6	116.3	164.5	11.2	15.2	21.1
4/02	82.3	114.6	158.1	11.2	15.2	21.6
5/02	81.6	112.9	154.4	11.4	15.4	22.2
6/02	81.5	111.1	152.7	11.3	15.3	22.0
7/02	81.9	109.5	150.8	11.4	15.2	22.0
8/02	81.6	108.0	148.1	11.3	15.0	22.2
9/02	81.4	106.4	145.0	11.3	14.9	22.5
10/02	80.2	104.9	141.1	11.2	14.7	22.8
11/02	80.3	103.4	137.0	11.1	14.7	23.5
12/02	80.0	101.9	132.4	11.0	14.7	24.2
1/03	78.9	100.3	125.4	11.3	14.8	24.7
2/03	77.6	98.9	119.5	11.3	14.8	25.0
3/03	76.6	97.7	118.4	11.2	14.8	24.9
4/03	74.8	96.6	118.7	11.4	14.8	24.5
5/03	74.0	95.6	119.4	11.6	14.7	23.6
6/03	73.4	94.8	119.8	11.3	14.7	22.8
7/03	73.2	93.9	119.0	11.1	14.7	22.1
8/03	73.1	92.8	117.7	11.1	14.8	21.8
9/03	72.7	91.7	116.4	11.2	14.8	21.4
10/03	71.7	90.6	114.6	11.2	14.8	21.1

Early Start Date (7/95)

11/03	71.1	89.6	110.8	10.5	14.7	20.5
12/03	70.6	88.4	105.4	9.9	14.4	19.7
1/04	70.1	87.3	103.2	9.5	14.3	19.7
2/04	69.9	86.5	102.0	9.2	14.1	19.8
3/04	70.0	85.7	100.4	9.0	14.0	19.5
4/04	69.9	84.8	98.2	8.9	13.8	19.1
5/04	69.7	83.6	96.6	8.8	13.8	18.6
6/04	69.5	82.5	94.6	8.7	13.8	17.9
7/04	69.4	81.8	93.8	8.7	13.7	17.0
8/04	69.3	81.1	92.7	8.8	13.6	16.5
9/04	69.0	80.3	92.0	8.9	13.5	16.7
10/04	68.8	79.6	91.8	9.0	13.4	16.9
11/04	68.5	78.9	91.4	9.0	13.3	17.1
12/04	68.2	78.2	90.8	9.0	13.3	17.4
1/05	68.2	77.5	90.1	9.0	13.1	17.7
2/05	68.2	76.9	89.1	9.2	12.9	17.6
3/05	68.2	76.4	88.2	9.3	12.7	17.4
4/05	68.3	75.9	87.0	9.2	12.5	16.9
5/05	68.3	75.3	85.4	9.1	12.2	16.1
6/05	68.3	74.8	83.2	9.1	11.8	14.7
7/05	68.3	74.2	80.5	9.1	11.5	13.6
8/05	67.9	73.5	78.5	8.9	11.2	13.7
9/05	67.6	72.9	77.6	8.5	10.9	13.4
10/05	67.4	72.3	77.1	8.1	10.6	13.0
11/05	67.4	72.0	76.9	8.0	10.5	12.7
12/05	67.2	71.6	76.7	8.0	10.3	12.4
1/06	67.1	71.3	76.5	8.0	10.1	11.7
2/06	67.0	70.9	76.2	8.0	9.9	11.2
3/06	67.0	70.6	75.2	7.9	9.8	11.0
4/06	67.0	70.3	74.2	7.2	9.1	10.9
5/06	67.0	70.1	74.0	7.4	9.2	11.1
6/06	67.0	69.9	73.5	7.6	9.4	11.4

Nominal Start Date (8/96)

	Solar Flux			Geomagnetic Index		
DATE	-2 sigma	mean	+2 sigma	-2 sigma	mean	+2 sigma
8/96	67.0	69.6	73.3	7.6	9.5	11.5
9/96	67.0	69.7	73.4	7.7	9.6	11.7
10/96	67.0	70.0	74.0	7.7	9.7	11.8
11/96	67.0	70.4	74.5	7.6	9.7	11.9
12/96	67.0	70.7	74.9	7.4	9.7	11.9
1/97	67.1	71.1	76.2	7.3	9.9	12.2
2/97	67.2	71.6	78.4	7.2	10.0	12.5
3/97	67.3	72.2	79.8	7.3	10.3	12.9
4/97	67.4	72.8	81.5	7.8	10.6	13.3
5/97	67.5	73.6	84.1	8.1	10.9	14.1
6/97	67.7	74.5	87.7	8.2	11.2	15.1
7/97	67.9	75.7	93.4	8.3	11.5	15.7
8/97	68.0	77.0	97.9	8.3	11.8	15.9
9/97	68.0	78.4	101.7	8.3	12.0	16.4
10/97	68.0	80.1	107.7	8.5	12.3	17.4
11/97	68.0	82.0	114.5	8.4	12.7	18.4
12/97	68.1	84.0	121.1	8.5	12.9	18.7
1/98	68.4	86.2	129.1	8.7	13.1	18.8
2/98	68.5	88.5	137.6	9.0	13.2	18.6
3/98	68.6	91.0	143.4	9.3	13.2	18.3
4/98	68.8	93.7	147.6	9.7	13.2	18.1
5/98	68.7	96.3	151.7	9.5	13.4	18.4
6/98	68.8	98.9	155.7	9.3	13.5	18.4
7/98	69.2	101.6	160.1	9.0	13.5	17.6
8/98	69.7	104.4	164.8	9.0	13.6	17.1
9/98	70.1	107.2	169.1	9.1	13.6	17.4
10/98	70.6	110.2	173.0	9.4	13.6	17.4
11/98	70.7	113.2	177.1	9.8	13.8	18.5
12/98	71.3	116.2	186.1	10.0	14.0	19.9
1/99	72.2	119.3	191.5	10.0	14.1	19.9
2/99	72.6	122.0	194.3	10.1	14.1	19.9
3/99	73.3	124.3	196.9	10.4	14.1	20.1
4/99	73.9	126.5	199.6	10.2	14.2	20.4
5/99	74.1	128.6	204.2	10.3	14.2	20.8
6/99	74.4	131.0	210.6	10.6	14.1	20.9
7/99	74.5	133.3	214.8	10.6	14.0	21.0
8/99	74.6	135.6	217.2	10.5	14.0	21.2
9/99	74.5	137.6	221.6	10.4	14.1	21.6
10/99	74.1	139.6	226.9	10.6	14.1	22.1
11/99	73.6	141.4	229.9	10.8	14.0	22.2
12/99	73.5	143.2	231.7	10.7	13.7	21.0
1/00	73.6	144.6	233.7	10.4	13.4	20.1
2/00	74.0	145.6	235.6	10.5	13.3	19.8
3/00	75.1	146.7	238.8	10.7	13.3	19.3
4/00	75.8	147.2	242.8	10.8	13.3	19.2
5/00	76.5	147.7	245.2	11.0	13.4	19.0
6/00	78.1	148.1	244.5	10.7	13.3	18.8
7/00	80.1	148.4	243.3	10.8	13.4	18.6
8/00	82.5	148.7	244.7	10.6	13.4	18.6

Nominal Start Date (8/96)

9/00	84.0	148.2	245.7	10.2	13.4	18.3
10/00	85.5	146.8	243.3	10.6	13.5	18.2
11/00	87.9	145.7	239.4	11.3	13.8	18.7
12/00	89.5	145.1	235.0	11.4	14.1	19.2
1/01	92.2	144.9	232.9	11.3	14.2	19.6
2/01	93.8	144.9	233.3	11.3	14.4	20.3
3/01	94.9	144.7	233.1	11.5	14.6	21.0
4/01	95.0	144.2	231.2	11.6	14.8	21.4
5/01	94.7	143.5	229.1	11.6	14.8	21.2
6/01	94.9	142.7	228.1	11.8	14.7	20.4
7/01	96.5	142.3	227.6	12.1	14.8	20.7
8/01	97.3	142.1	226.7	12.2	15.1	21.9
9/01	96.8	141.3	225.6	12.0	15.2	22.7
10/01	96.0	140.1	223.0	11.6	15.1	22.7
11/01	96.0	138.4	218.6	11.2	15.1	22.3
12/01	96.6	136.8	215.2	11.2	15.1	21.7
1/02	96.7	135.5	212.0	11.2	15.1	21.5
2/02	95.1	134.3	206.9	11.2	15.1	22.1
3/02	95.0	133.0	204.0	11.3	15.5	23.1
4/02	96.3	131.6	203.6	11.3	15.6	23.5
5/02	96.5	129.8	200.4	11.2	15.6	23.4
6/02	94.7	128.3	196.8	11.1	15.7	23.3
7/02	93.6	127.3	195.7	10.8	15.5	23.1
8/02	93.5	126.5	194.8	10.9	15.7	22.2
9/02	91.9	125.1	191.5	11.1	15.6	22.1
10/02	88.7	123.5	187.4	11.7	15.6	22.2
11/02	86.6	122.3	182.9	11.6	15.8	22.5
12/02	87.8	121.5	178.6	11.5	15.9	22.6
1/03	86.5	120.5	176.3	11.3	15.8	22.5
2/03	85.9	119.5	174.9	11.3	15.7	21.6
3/03	85.0	117.9	171.1	11.3	15.4	21.0
4/03	83.6	116.3	164.5	11.2	15.2	21.1
5/03	82.3	114.6	158.1	11.2	15.2	21.6
6/03	81.6	112.9	154.4	11.4	15.4	22.2
7/03	81.5	111.1	152.7	11.3	15.3	22.0
8/03	81.9	109.5	150.8	11.4	15.2	22.0
9/03	81.6	108.0	148.1	11.3	15.0	22.2
10/03	81.4	106.4	145.0	11.3	14.9	22.5
11/03	80.2	104.9	141.1	11.2	14.7	22.8
12/03	80.3	103.4	137.0	11.1	14.7	23.5
1/04	80.0	101.9	132.4	11.0	14.7	24.2
2/04	78.9	100.3	125.4	11.3	14.8	24.7
3/04	77.6	98.9	119.5	11.3	14.8	25.0
4/04	76.6	97.7	118.4	11.2	14.8	24.9
5/04	74.8	96.6	118.7	11.4	14.8	24.5
6/04	74.0	95.6	119.4	11.6	14.7	23.6
7/04	73.4	94.8	119.8	11.3	14.7	22.8
8/04	73.2	93.9	119.0	11.1	14.7	22.1
9/04	73.1	92.8	117.7	11.1	14.8	21.8
10/04	72.7	91.7	116.4	11.2	14.8	21.4
11/04	71.7	90.6	114.6	11.2	14.8	21.1

Nominal Start Date (8/96)

12/04	71.1	89.6	110.8	10.5	14.7	20.5
1/05	70.6	88.4	105.4	9.9	14.4	19.7
2/05	70.1	87.3	103.2	9.5	14.3	19.7
3/05	69.9	86.5	102.0	9.2	14.1	19.8
4/05	70.0	85.7	100.4	9.0	14.0	19.5
5/05	69.9	84.8	98.2	8.9	13.8	19.1
6/05	69.7	83.6	96.6	8.8	13.8	18.6
7/05	69.5	82.5	94.6	8.7	13.8	17.9
8/05	69.4	81.8	93.8	8.7	13.7	17.0
9/05	69.3	81.1	92.7	8.8	13.6	16.5
10/05	69.0	80.3	92.0	8.9	13.5	16.7
11/05	68.8	79.6	91.8	9.0	13.4	16.9
12/05	68.5	78.9	91.4	9.0	13.3	17.1
1/06	68.2	78.2	90.8	9.0	13.3	17.4
2/06	68.2	77.5	90.1	9.0	13.1	17.7
3/06	68.2	76.9	89.1	9.2	12.9	17.6
4/06	68.2	76.4	88.2	9.3	12.7	17.4
5/06	68.3	75.9	87.0	9.2	12.5	16.9
6/06	68.3	75.3	85.4	9.1	12.2	16.1
7/06	68.3	74.8	83.2	9.1	11.8	14.7
8/06	68.3	74.2	80.5	9.1	11.5	13.6
9/06	67.9	73.5	78.5	8.9	11.2	13.7
10/06	67.6	72.9	77.6	8.5	10.9	13.4
11/06	67.4	72.3	77.1	8.1	10.6	13.0
12/06	67.4	72.0	76.9	8.0	10.5	12.7
1/07	67.2	71.6	76.7	8.0	10.3	12.4
2/07	67.1	71.3	76.5	8.0	10.1	11.7
3/07	67.0	70.9	76.2	8.0	9.9	11.2
4/07	67.0	70.6	75.2	7.9	9.8	11.0
5/07	67.0	70.3	74.2	7.2	9.1	10.9
6/07	67.0	70.1	74.0	7.4	9.2	11.1
7/07	67.0	69.9	73.5	7.6	9.4	11.4

Late Start Date (9/96)

	Solar Flux			Geomagnetic Index		
DATE	-2 sigma	mean	+2 sigma	-2 sigma	mean	+2 sigma
9/97	67.0	69.6	73.3	7.6	9.5	11.5
10/97	67.0	69.7	73.4	7.7	9.6	11.7
11/97	67.0	70.0	74.0	7.7	9.7	11.8
12/97	67.0	70.4	74.5	7.6	9.7	11.9
1/98	67.0	70.7	74.9	7.4	9.7	11.9
2/98	67.1	71.1	76.2	7.3	9.9	12.2
3/98	67.2	71.6	78.4	7.2	10.0	12.5
4/98	67.3	72.2	79.8	7.3	10.3	12.9
5/98	67.4	72.8	81.5	7.8	10.6	13.3
6/98	67.5	73.6	84.1	8.1	10.9	14.1
7/98	67.7	74.5	87.7	8.2	11.2	15.1
8/98	67.9	75.7	93.4	8.3	11.5	15.7
9/98	68.0	77.0	97.9	8.3	11.8	15.9
10/98	68.0	78.4	101.7	8.3	12.0	16.4
11/98	68.0	80.1	107.7	8.5	12.3	17.4
12/98	68.0	82.0	114.5	8.4	12.7	18.4
1/99	68.1	84.0	121.1	8.5	12.9	18.7
2/99	68.4	86.2	129.1	8.7	13.1	18.8
3/99	68.5	88.5	137.6	9.0	13.2	18.6
4/99	68.6	91.0	143.4	9.3	13.2	18.3
5/99	68.8	93.7	147.6	9.7	13.2	18.1
6/99	68.7	96.3	151.7	9.5	13.4	18.4
7/99	68.8	98.9	155.7	9.3	13.5	18.4
8/99	69.2	101.6	160.1	9.0	13.5	17.6
9/99	69.7	104.4	164.8	9.0	13.6	17.1
10/99	70.1	107.2	169.1	9.1	13.6	17.4
11/99	70.6	110.2	173.0	9.4	13.6	17.4
12/99	70.7	113.2	177.1	9.8	13.8	18.5
1/00	71.3	116.2	186.1	10.0	14.0	19.9
2/00	72.2	119.3	191.5	10.0	14.1	19.9
3/00	72.6	122.0	194.3	10.1	14.1	19.9
4/00	73.3	124.3	196.9	10.4	14.1	20.1
5/00	73.9	126.5	199.6	10.2	14.2	20.4
6/00	74.1	128.6	204.2	10.3	14.2	20.8
7/00	74.4	131.0	210.6	10.6	14.1	20.9
8/00	74.5	133.3	214.8	10.6	14.0	21.0
9/00	74.6	135.6	217.2	10.5	14.0	21.2
10/00	74.5	137.6	221.6	10.4	14.1	21.6
11/00	74.1	139.6	226.9	10.6	14.1	22.1
12/00	73.6	141.4	229.9	10.8	14.0	22.2
1/01	73.5	143.2	231.7	10.7	13.7	21.0
2/01	73.6	144.6	233.7	10.4	13.4	20.1
3/01	74.0	145.6	235.6	10.5	13.3	19.8
4/01	75.1	146.7	238.8	10.7	13.3	19.3
5/01	75.8	147.2	242.8	10.8	13.3	19.2
6/01	76.5	147.7	245.2	11.0	13.4	19.0
7/01	78.1	148.1	244.5	10.7	13.3	18.8
8/01	80.1	148.4	243.3	10.8	13.4	18.6
9/01	82.5	148.7	244.7	10.6	13.4	18.6

Late Start Date (9/96)

10/01	84.0	148.2	245.7	10.2	13.4	18.3
11/01	85.5	146.8	243.3	10.6	13.5	18.2
12/01	87.9	145.7	239.4	11.3	13.8	18.7
1/02	89.5	145.1	235.0	11.4	14.1	19.2
2/02	92.2	144.9	232.9	11.3	14.2	19.6
3/02	93.8	144.9	233.3	11.3	14.4	20.3
4/02	94.9	144.7	233.1	11.5	14.6	21.0
5/02	95.0	144.2	231.2	11.6	14.8	21.4
6/02	94.7	143.5	229.1	11.6	14.8	21.2
7/02	94.9	142.7	228.1	11.8	14.7	20.4
8/02	96.5	142.3	227.6	12.1	14.8	20.7
9/02	97.3	142.1	226.7	12.2	15.1	21.9
10/02	96.8	141.3	225.6	12.0	15.2	22.7
11/02	96.0	140.1	223.0	11.6	15.1	22.7
12/02	96.0	138.4	218.6	11.2	15.1	22.3
1/03	96.6	136.8	215.2	11.2	15.1	21.7
2/03	96.7	135.5	212.0	11.2	15.1	21.5
3/03	95.1	134.3	206.9	11.2	15.1	22.1
4/03	95.0	133.0	204.0	11.3	15.5	23.1
5/03	96.3	131.6	203.6	11.3	15.6	23.5
6/03	96.5	129.8	200.4	11.2	15.6	23.4
7/03	94.7	128.3	196.8	11.1	15.7	23.3
8/03	93.6	127.3	195.7	10.8	15.5	23.1
9/03	93.5	126.5	194.8	10.9	15.7	22.2
10/03	91.9	125.1	191.5	11.1	15.6	22.1
11/03	88.7	123.5	187.4	11.7	15.6	22.2
12/03	86.6	122.3	182.9	11.6	15.8	22.5
1/04	87.8	121.5	178.6	11.5	15.9	22.6
2/04	86.5	120.5	176.3	11.3	15.8	22.5
3/04	85.9	119.5	174.9	11.3	15.7	21.6
4/04	85.0	117.9	171.1	11.3	15.4	21.0
5/04	83.6	116.3	164.5	11.2	15.2	21.1
6/04	82.3	114.6	158.1	11.2	15.2	21.6
7/04	81.6	112.9	154.4	11.4	15.4	22.2
8/04	81.5	111.1	152.7	11.3	15.3	22.0
9/04	81.9	109.5	150.8	11.4	15.2	22.0
10/04	81.6	108.0	148.1	11.3	15.0	22.2
11/04	81.4	106.4	145.0	11.3	14.9	22.5
12/04	80.2	104.9	141.1	11.2	14.7	22.8
1/05	80.3	103.4	137.0	11.1	14.7	23.5
2/05	80.0	101.9	132.4	11.0	14.7	24.2
3/05	78.9	100.3	125.4	11.3	14.8	24.7
4/05	77.6	98.9	119.5	11.3	14.8	25.0
5/05	76.6	97.7	118.4	11.2	14.8	24.9
6/05	74.8	96.6	118.7	11.4	14.8	24.5
7/05	74.0	95.6	119.4	11.6	14.7	23.6
8/05	73.4	94.8	119.8	11.3	14.7	22.8
9/05	73.2	93.9	119.0	11.1	14.7	22.1
10/05	73.1	92.8	117.7	11.1	14.8	21.8
11/05	72.7	91.7	116.4	11.2	14.8	21.4
12/05	71.7	90.6	114.6	11.2	14.8	21.1

Late Start Date (9/96)

1/06	71.1	89.6	110.8	10.5	14.7	20.5
2/06	70.6	88.4	105.4	9.9	14.4	19.7
3/06	70.1	87.3	103.2	9.5	14.3	19.7
4/06	69.9	86.5	102.0	9.2	14.1	19.8
5/06	70.0	85.7	100.4	9.0	14.0	19.5
6/06	69.9	84.8	98.2	8.9	13.8	19.1
7/06	69.7	83.6	96.6	8.8	13.8	18.6
8/06	69.5	82.5	94.6	8.7	13.8	17.9
9/06	69.4	81.8	93.8	8.7	13.7	17.0
10/06	69.3	81.1	92.7	8.8	13.6	16.5
11/06	69.0	80.3	92.0	8.9	13.5	16.7
12/06	68.8	79.6	91.8	9.0	13.4	16.9
1/07	68.5	78.9	91.4	9.0	13.3	17.1
2/07	68.2	78.2	90.8	9.0	13.3	17.4
3/07	68.2	77.5	90.1	9.0	13.1	17.7
4/07	68.2	76.9	89.1	9.2	12.9	17.6
5/07	68.2	76.4	88.2	9.3	12.7	17.4
6/07	68.3	75.9	87.0	9.2	12.5	16.9
7/07	68.3	75.3	85.4	9.1	12.2	16.1
8/07	68.3	74.8	83.2	9.1	11.8	14.7
9/07	68.3	74.2	80.5	9.1	11.5	13.6
10/07	67.9	73.5	78.5	8.9	11.2	13.7
11/07	67.6	72.9	77.6	8.5	10.9	13.4
12/07	67.4	72.3	77.1	8.1	10.6	13.0
1/08	67.4	72.0	76.9	8.0	10.5	12.7
2/08	67.2	71.6	76.7	8.0	10.3	12.4
3/08	67.1	71.3	76.5	8.0	10.1	11.7
4/08	67.0	70.9	76.2	8.0	9.9	11.2
5/08	67.0	70.6	75.2	7.9	9.8	11.0
6/08	67.0	70.3	74.2	7.2	9.1	10.9
7/08	67.0	70.1	74.0	7.4	9.2	11.1
8/08	67.0	69.9	73.5	7.6	9.4	11.4

Appendix B

Development of the Tier 2 EVA Assembly Time Estimates

As mentioned earlier, the lack of station-based crew in the Tier 2 assembly analysis created assembly EVA shortfalls in the assembly sequence process that had to be accommodated. Depending upon the hardware delivered and the criticality of the hardware needs for station functionality, the EVA tasks were either deferred to later flights or the number of EVAs per flight was increased. In most cases, when an EVA was moved from one flight to another, all of the tasks within that particular EVA were transferred. In a few cases where this was not possible, EVA task times were estimated by similar or known task times as described in the International Space Station Alpha Integrated Operations Scenarios (ISSA IOS), dated September 1994, and the Integrated Operations Scenarios, dated February 1993 (IOS '93). Where there were major discrepancies in total EVA hour estimates, the ISSA Assembly Overviews developed by the Mission Operations Directorate (MOD) at JSC for the 9/28/94 Baseline ISSA Assembly Sequence took precedence and the task times were adjusted accordingly.

EVA Timeline

Stage #	Flight	EVA #	EVA (hours)	Tasks
1	1A	None	----	
2	2A	EVA1	5:40	Connect Bus-1 to Node1 EPS Umbilicals
				Connect PMA2 to Node1 Umbilicals
				Connect PMA3 to Node1 Umbilicals
		EVA2	3:00	Release CBM Cover Launch Restraints
				Install Node1 Trunnion & Keel Pin Covers
3	3A	EVA1	5:05	Connect Z1 truss to Node1 umbilicals
				Deploy Ku-Band Antenna
				Stow Z1 Keel Pin
		EVA2	4:25	Release 2 HP Gas containers from ULC & install on spacer truss
				Connect 1 O2, 1 N2 gas utilities
				Transfer EVAS Equipment from SLP to Station
		EVA3	4:25	Release 2 HP Gas containers from ULC & install on spacer truss
				Connect 1 O2, 1 N2 gas utilities
				Transfer EVAS Equipment from SLP to Station
4	4A	EVA1	5:40	Install S-band RFG on P6 IEA
				Attach ITS P6 to ITS Z1
				Connect Power, Data, and RF Utilities from ITS P6 to ITS Z1
				Configure P6 EEATCS QDs
		EVA2	4:30	Perform Upper EPS Prep
				Rotate IEA Keel Pin
				Perform Lower EPS Prep
				Release P6 PV Rad Cinches
				Release P6 PV Rad Winches
				Reconfigure Z1 Patch Panels to Provide P6 Power to U.S. Elements
5	5A	EVA1	5:25	Disconnect PMA2 umbilicals
				Reconfigure APCU jumpers
				Remove Radiator-1&2 cinches
				Remove Radiator-1&2 winches
				Attach PMA2 to Z1 CBM
		EVA2	4:55	Deploy Z1/Lab Utility Tray
				Connect Umbilicals
				Vent Lab Heat Exchangers
				Connect Ku-Band umbilicals
				Install Lab PDGF
		EVA3	5:10	Remove/Stow Lab CBM thermal blanket
				Disconnect PMA2 from Z1 CBM
				Connect PMA2 to Lab umbilicals

EVA Timeline

Stage #	Flight	EVA #	EVA (hours)	Tasks
6	6A	EVA1	5:20	Install Lab Cradle Assembly (LCA) on Lab
				Install LCA capture latch umbilicals to Lab aft endcone
				Install PDGF umbilicals to Lab Fwd endcone
				Disconnect umbilicals from PMA3 to Node1
				Install UHF antenna to Lab Nadir
		EVA2	4:20	Connect PDGF umbilicals from SSRMS to Lab
				Deploy SSRMS
				Install Node1 external camera
		EVA3	2:00	Reconfigure PDGF umbilicals to Lab PDGF
				Release and stow SSRMS umbilicals on FSE
7	UF-1	0	0:00	
8	7A	EVA1	5:20	Release 2 HP Gas containers from ULC & install on Airlock
				Connect 1 O2, 1 N2 Gas utilities
		EVA2	5:20	Release 2 HP Gas containers from ULC & install on Airlock
				Connect 1 O2, 1 N2 Gas utilities
9	8A	EVA1	6:00	Install Fwd S0 MTS struts on Lab
				Install Aft S0 MTS struts on Lab
				Relieve loads on LCA guide cones
		EVA2	5:05	Connect Lab/S0 umbilicals
				Install Lab fwd umbilicals
				Install PDGF umbilical
				Release MT
				Attach TUS cables to MT
10	Bus	EVA1	4:20	Connect Bus-1 to ITS Z1 EPS Umbilicals
		EVA2	4:00	Remove and stow port keel pin/drag link
				Install Ceta-to-MT shock absorbers
				Deploy EV_CPDS
				Release PWP launch restraint
				Remove plasma contactor covers
		EVA3	6:00	Remove and stow stbd keel pin/drag link
				Install airlock spur
				Install Node1 to S0 umbilical tray
				Stow Lab cradle assembly umbilicals
11	UF-2	EVA1	4:45	Secure MBS
				Deploy POA
				Remove MBS Avionics Thermal Blanket
				MBS Checkout

EVA Timeline

Stage #	Flight	EVA #	EVA (hours)	Tasks
12	9A	EVA1	5:50	Connect upper and lower tray utilities
				Remove radiator beam launch locks (18)
				Deploy S-Band and IVA
		EVA2	5:50	Reconfigure AUAI umbilicals to S-Band
				Install S1 outboard nadir camera
				Relocate Node1 camera to Lab
				Connect Ammonia tank N2 umbilicals
				Deploy CETA Cart
				Rotate MT stop
				Connect PMA3 to Node 1 umbilicals
13	10A	EVA1	5:30	Remove and stow inboard keel pin
				Remove and stow outboard keel pin
				Deploy Light Stanchion
				Connect CETA cart to MT
				Install OTD on CETA Cart
		EVA2	3:20	Disconnect PMA2-to-Lab umbilical
				Release Cupola window launch restraints
				Remove CBM cover launch restraints
		EVA3	4:35	Install Node2 trunnion/keel pin covers (5)
				Install Node2 fwd-to-Node2 aft umbilical tray
				Install Node2 fwd-to-Node2 aft umbilical tray
		EVA4	5:05	Connect PMA2-to-Node2 umbilical
				Install S0 to Node2 fwd umbilical tray
				Install S0 to Node2 fwd umbilical tray
14	11A	EVA1	4:50	Perform ITS P1 to ITS S0 utility connections
				Deploy UHF antenna
				Release Port TCS Radiator Beam Launch Locks (18)
		EVA2	4:55	Deploy and attach upper and lower external cameras
				MT/SSRMS assest EVA camera installation
				Remove ITS P1 Stbd Keel Pin / Drag Link and stow
		EVA3	4:35	CETA cart preparation
				Remove ITS P1 Port Keel Pin/Drag link and stow
				Rotate S0 stbd MT Rail stop and stow
				Connect Ammonia tank umbilicals
15	UF-3	None	0:00	

EVA Timeline

Stage #	Flight	EVA #	EVA (hours)	Tasks
16	1 J/A	EVA1	5:00	Relocate EVAS equipment to CETA carts
		EVA2	4:40	Retrieve S-Band antenna
				MT/SSRMS relocate S-Band antenna to P1 truss
				Install S-band antenna
		EVA3	4:35	Install APM/JEM DDCU Umbilical Trays
		EVA4	5:40	Relocate external camera from S1-IL to S1-OL
				Install first High Pressure O2 tank
				Relocate replacement HP O2 tank on ULC
				Remove old HP O2 tank and place on ULC
				Install replacement HP O2 tank on Airlock
				Stow ULC on MBS
		EVA5	5:55	Install second High Pressure O2 tank
				Relocate replacement HP O2 tank on ULC
				Remove old HP O2 tank and place on ULC
				Install replacement HP O2 tank on Airlock
				Install trunnion covers on ELM-PS
		EVA6	3:00	Release SPDM launch restraints
				SSRMS stows SPDM on MBS PDGF
17	12A	EVA1	2:12	Connect ITS P3 to ITS P1 Utilities
				Rotate P1 MT Stop
				Rotate P4 Keel Pin
		EVA2	4:45	Deploy Port ULCASs (2) and Install 2 P3 SARJ braces
				Install remaining P3 SARJ braces
				Remove and Stow ITS P3 Keel Pin
				Install 4 P4 SARJ braces

EVA Timeline

Stage #	Flight	EVA #	EVA (hours)	Tasks
18	12Ap	EVA1	4:44	Perform upper EPS preparation
				Perform lower EPS preparation
		EVA2	5:36	Release PV Radiator Cinches
				Release PV Radiator Winches
				Connect Lab Ch 2B loads to MBSU outputs
				Utility DDCU Jumper Config at F1
				MBSU-DDCU Jumper Config at P1
				Core SPDA Jumper Config at S0
				Remove and Stow SARJ Race Ring Launch Locks and Launch Restraints
		EVA3	5:20	Connect P1 TCS to Lab Heat Exchanger Umbilicals
				Engage SARJ DLAs
				Wait for Lab Reconfiguration
				Connect Lab Ch 4B loads to MBSU Outputs
				Utility DDCU Jumpers Config at S1
				MBSU-DDCU Jumper Config at S1
				Core SPDA Jumper Config at S0
		EVA4	3:45	Connect S1 TCS to Lab Heat Exchanger Umbilicals
				Stow (winch down) stbd ETCS radiator
				Stow (winch down) aft ETCS radiator
		EVA5	5:40	P5 Installation
				Translate P5 on MT to P3
				Attach P5 to P4
				Connect P4/P5 Power & Data Utilities
				PFR Setup to remove GF
				SSRMS Grapple GF and Remove GF Bracket
				Translate GF Bracket from P3 to S0
				Install GF Brackets on P6 Stbd.
		EVA6	3:30	Unstow P4 AJIS strut and P4, P5, P6 MT rails, temporarily stow on MBS and translate to P3
		EVA7	5:30	Install P4 AJIS strut
				Install P4/P5 MT rails
19	UF-4p	0	0:00	------------
20	BF-1	0	0:00	-------------
21	13A	EVA1	2:10	Connect S1 to S3/S4 Utilities (Power and Data)
				Rotate S1 MT Rail Stop
				Rotate S4 Keel Pin
		EVA2	6:00	Relocate P6 Stbd ETCS Radiator to Function as S4 PV Radiator
				Stow Grapple Fixture on P5

EVA Timeline

Stage #	Flight	EVA #	EVA (hours)	Tasks
22	13Ap	EVA1	9:15	Release SARJ Race Ring Launch Locks and SARJ Launch Restraints
				Engage SARJ DLAs
				Prep Upper EPS Equipment
				Prep Lower EPS Equipment
				Rigidize 4 S4 SARJ Braces
		EVA2	5:55	Disconnect Bus-1 to P6 Umbilicals
				Remove S3 Keel Pin and Drag Link
				Deploy 2 PAS and Attach 4 S3 SARJ Braces
		EVA3	3:30	Install S4 AJIS strut
				Install S4 MT rails
				Rotate S3 MT rail stop
		EVA4	3:50	Stow P6 PV Radiator
				Disconnect P6 to Z1 Utilities
				Detach P6 from Z1
				Disconnect Z1 to S0/MBSU Power Jumpers
				Reconfigure MBSU-2B & 4B Input Power Feeds
		EVA5	5:10	Attach P6 to P5
				Connect P6 to P5 Power and Data Utilities
				Unstow P6 PV Radiator
				Deploy 2 PAS
		EVA6	4:10	Connect Bus-1 to Z1 umbilicals
				Install P6 MT rails
				Rotate P3 MT rail stop
				Stow P6 MT rail ends on P6
23	UF-5p	None	0:00	--------
24	1J	EVA1	5:35	Relocate S1-OL camera to S1-IU camera port
				Install JEM PM trunnion and keep pin covers
				Relocate Lab camera to S1-OU
				Remove JEM RMS thermal covers
				Install JEM PM cameras/lights
				Release CBM cover launch restraints
		EVA2	1:40	Connect PDGF utilities to JEM PM endcone
25	2E	EVA1	3:15	Install S5 on end of S4
26	UF-6p	None	0:00	
27	2 J/A	EVA1	3:15	Install JEM EF TV camera/lights
				Move camera from P1 inner-lower port to S1 inner-upper port

EVA Timeline

Stage #	Flight	EVA #	EVA (hours)	Tasks
28	15A	EVA1	5:40	Attach S6 to S5
				Connect S6 to S5 utilities (Power/Data)
				Install S4 AJIS strut
				Rotate S6 MT rails
		EVA2	6:00	Relocate P6 temp ETCS radiator to S6
		EVA3	6:00	Complete S6 PV radiator preparation
				Upper and lower EPS prep
				Rotate IEA keel pin
29	BF-2	None	0:00	
30	UF-7p	None	0:00	
31	14A	EVA1	6:00	Connect umbilicals to Centrifuge Module
32	1E	EVA1	1:30	Disconnect PMA3 to Node 1 Umbilicals
33	16A	EVA1	4:00	Connect Hab heat exchanger and power umbilicals & PDGF and PMA umbilicals
				Install Hab PDGF
		EVA2	4:40	Remove thermal cover from Hab nadir
				Connect PMA3 umbilicals to Hab nadir
34	17A	None	0:00	
35	18A	None	0:00	
36	19A	None	0:00	

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
August 1995

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Alternate Assembly Sequence Databook for the Tier 2 Bus-1 Option of the International Space Station

5. FUNDING NUMBERS
WU 478-87-00-01

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA
Langley Research Center
Hampton, VA 23681-0001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
NASA TM-110198

11. SUPPLEMENTARY NOTES
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12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified - Unlimited

Subject Category 18

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The JSC international Space Station program office requested that SSB prepare a databook to document the alternate space station assembly sequence known as Tier 2, which assumes that the Russian participation has been eliminated and that the functions that were supplied by the Russians (propulsion, resupply, initial attitude control, communications, etc.) are now supplied by the U. S. Tier 2 utilizes the Lockheed Bus-1 to replace much of the missing Russian functionality.

The space station at each stage of its buildup during the Tier 2 assembly sequence is characterized in terms of mass properties, functionality, resource balances, operations, logistics, attitude control, microgravity environment, and propellant usage.

The assembly sequence as analyzed was defined by JSC as a first iteration, with subsequent iterations required to address some of the issues that the analysis in this databook identified. Several significant issues were identified, including: less than desirable orbit lifetimes, shortage of EVA, large flight attitudes, poor microgravity environments, and reboost propellant shortages. Many of these issues can be resolved but at the cost of possible baseline modifications and revisions in the proposed Tier 2 assembly sequence.

14. SUBJECT TERMS
Space Station, Tier 2, Databook, Assembly Sequence

15. NUMBER OF PAGES
412

16. PRICE CODE
A18

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited